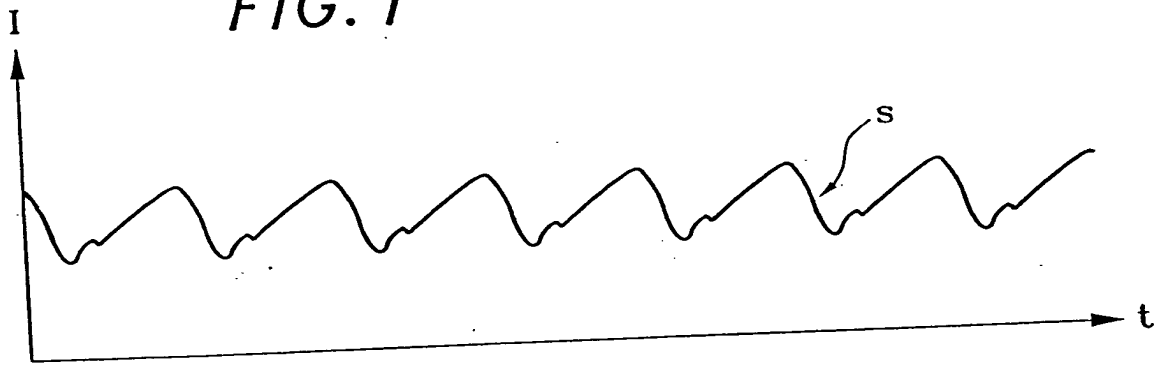
FIG. 1



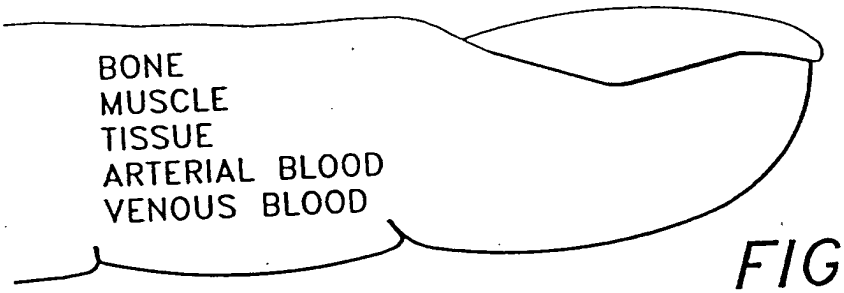
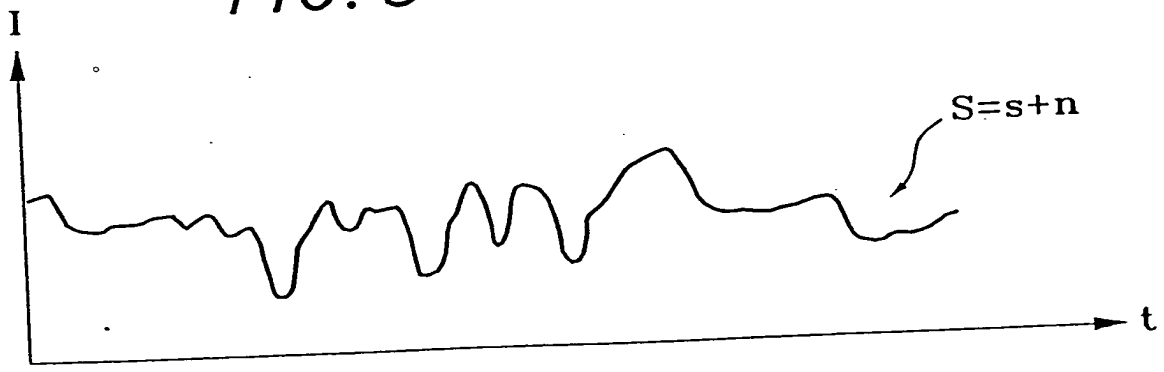


FIG. 2

FIG. 3



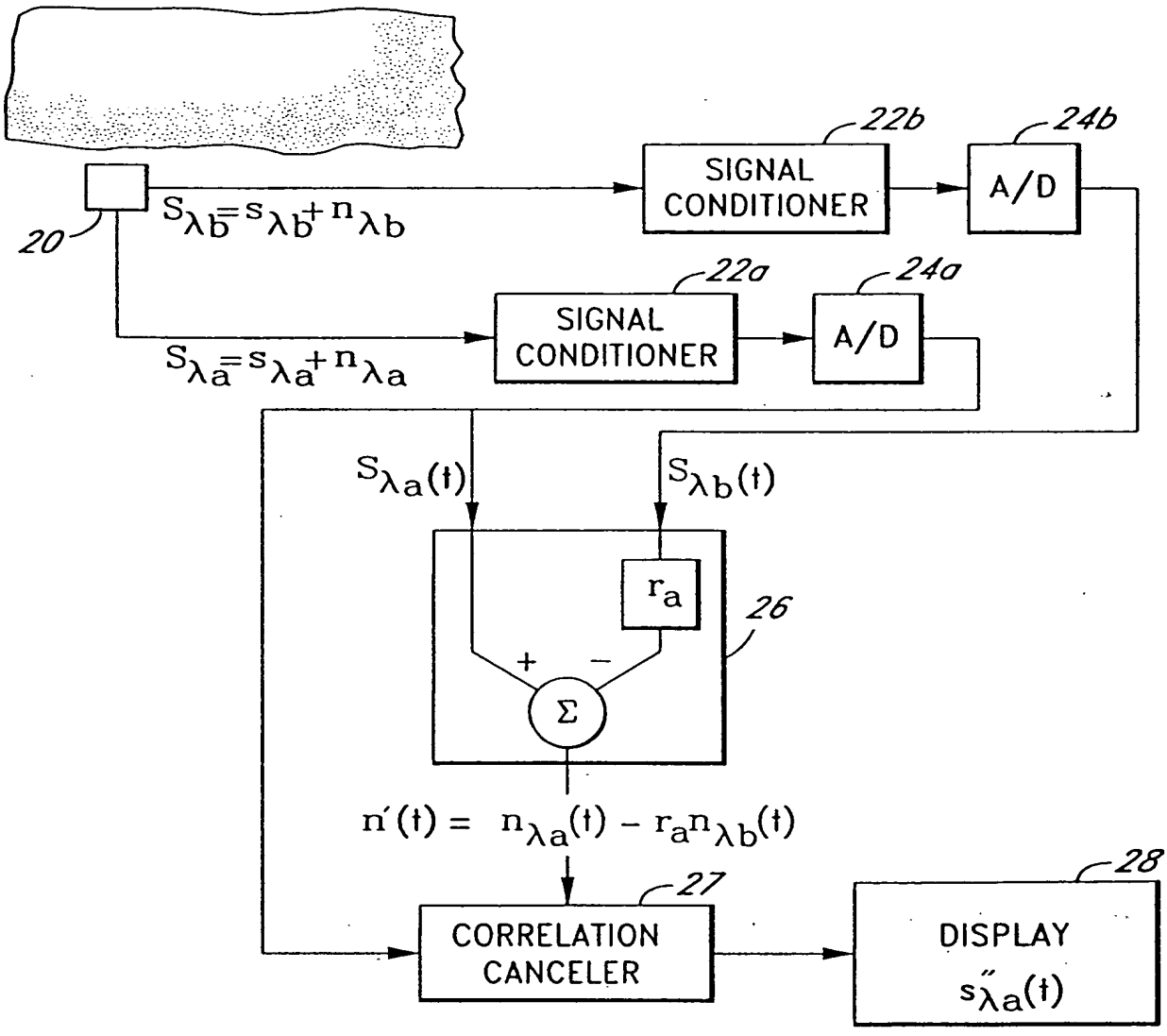

22b
24b
SIGNAL CONDITIONER
A/D
20
$S_{\lambda b}=s_{\lambda b}+n_{\lambda b}$
22a
24a
SIGNAL CONDITIONER
A/D
$S_{\lambda a}=s_{\lambda a}+n_{\lambda a}$
$S_{\lambda a}(t)$
$S_{\lambda b}(t)$
r_a
26
+
−
Σ
$n'(t) = n_{\lambda a}(t) - r_a n_{\lambda b}(t)$
27
28
CORRELATION CANCELER
DISPLAY
$s''_{\lambda a}(t)$

FIG. 4a

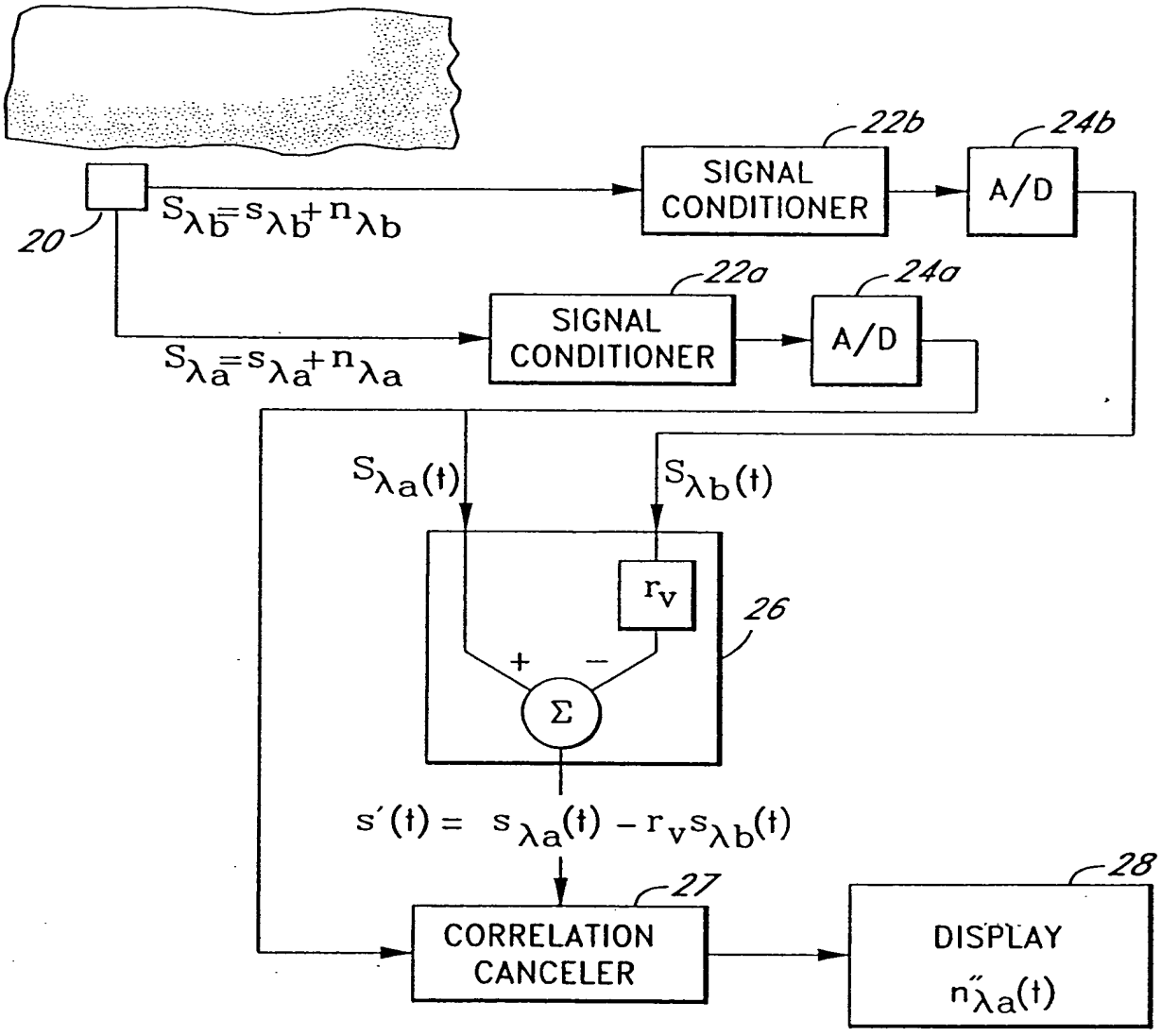

22b
24b
SIGNAL CONDITIONER
A/D
20
$S_{\lambda b}=s_{\lambda b}+n_{\lambda b}$
22a
24a
SIGNAL CONDITIONER
A/D
$S_{\lambda a}=s_{\lambda a}+n_{\lambda a}$
$S_{\lambda a}(t)$
$S_{\lambda b}(t)$
r_v
26
+
−
Σ
$s'(t) = s_{\lambda a}(t) - r_v s_{\lambda b}(t)$
27
28
CORRELATION CANCELER
DISPLAY
$n''_{\lambda a}(t)$

FIG. 4b

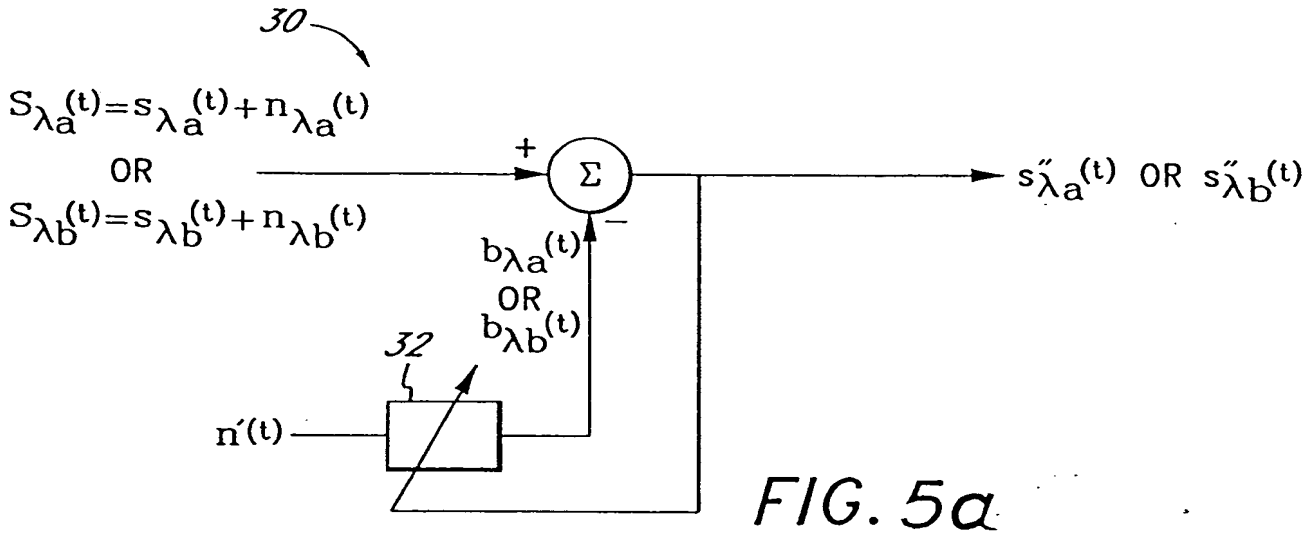

30
$S_{\lambda a}(t)=s_{\lambda a}(t)+n_{\lambda a}(t)$
OR
$S_{\lambda b}(t)=s_{\lambda b}(t)+n_{\lambda b}(t)$
+
Σ
−
$s''_{\lambda a}(t)$ OR $s''_{\lambda b}(t)$
$b_{\lambda a}(t)$
OR
$b_{\lambda b}(t)$
32
n'(t)

FIG. 5a

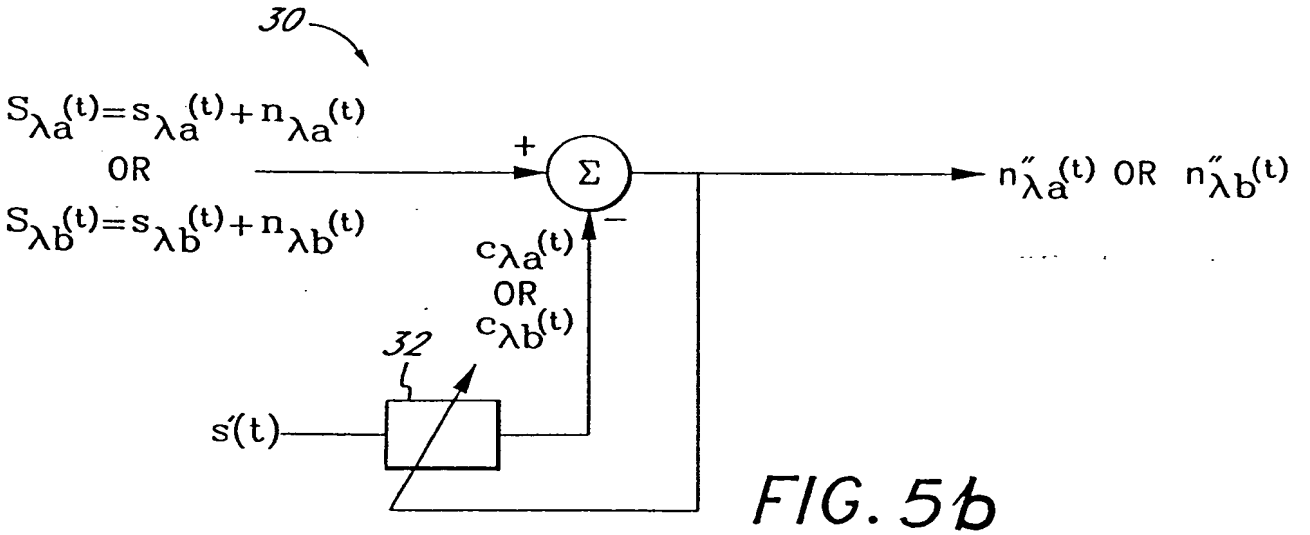

30
$S_{\lambda a}(t)=s_{\lambda a}(t)+n_{\lambda a}(t)$
OR
$S_{\lambda b}(t)=s_{\lambda b}(t)+n_{\lambda b}(t)$
+
Σ
−
$n''_{\lambda a}(t)$ OR $n''_{\lambda b}(t)$
$c_{\lambda a}(t)$
OR
$c_{\lambda b}(t)$
32
s'(t)

FIG. 5b

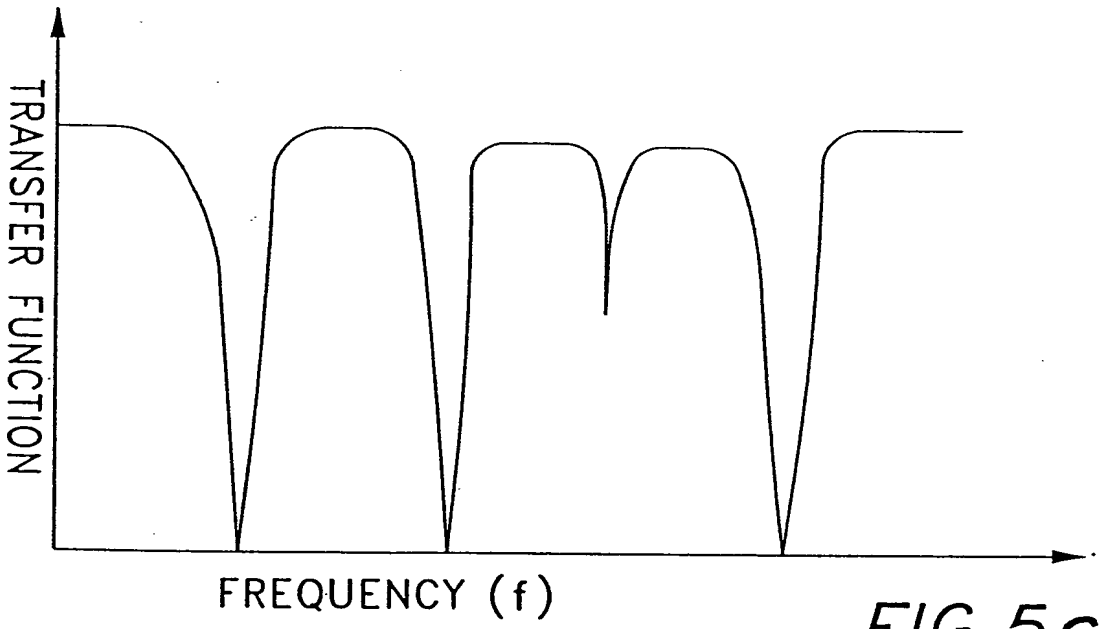


FIG. 5c

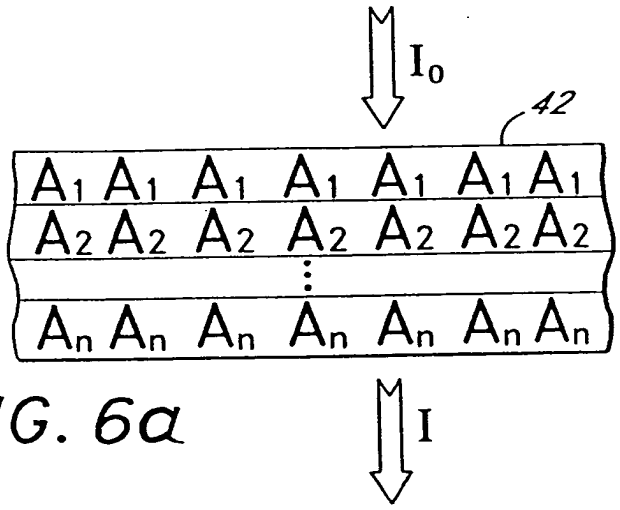


FIG. 6a

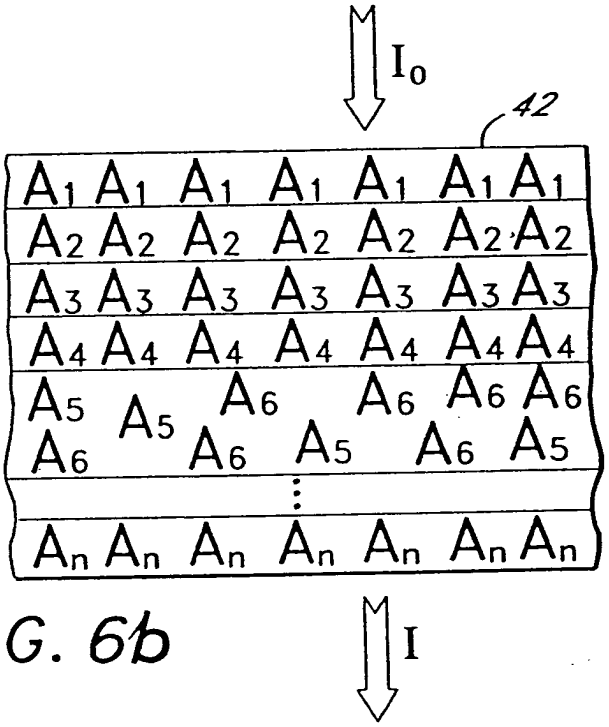


FIG. 6b

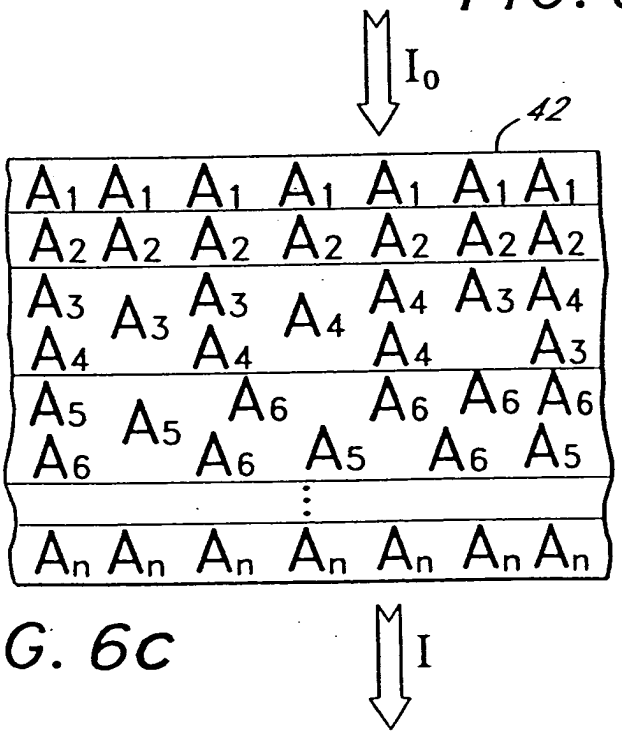


FIG. 6c

FIG. 7a

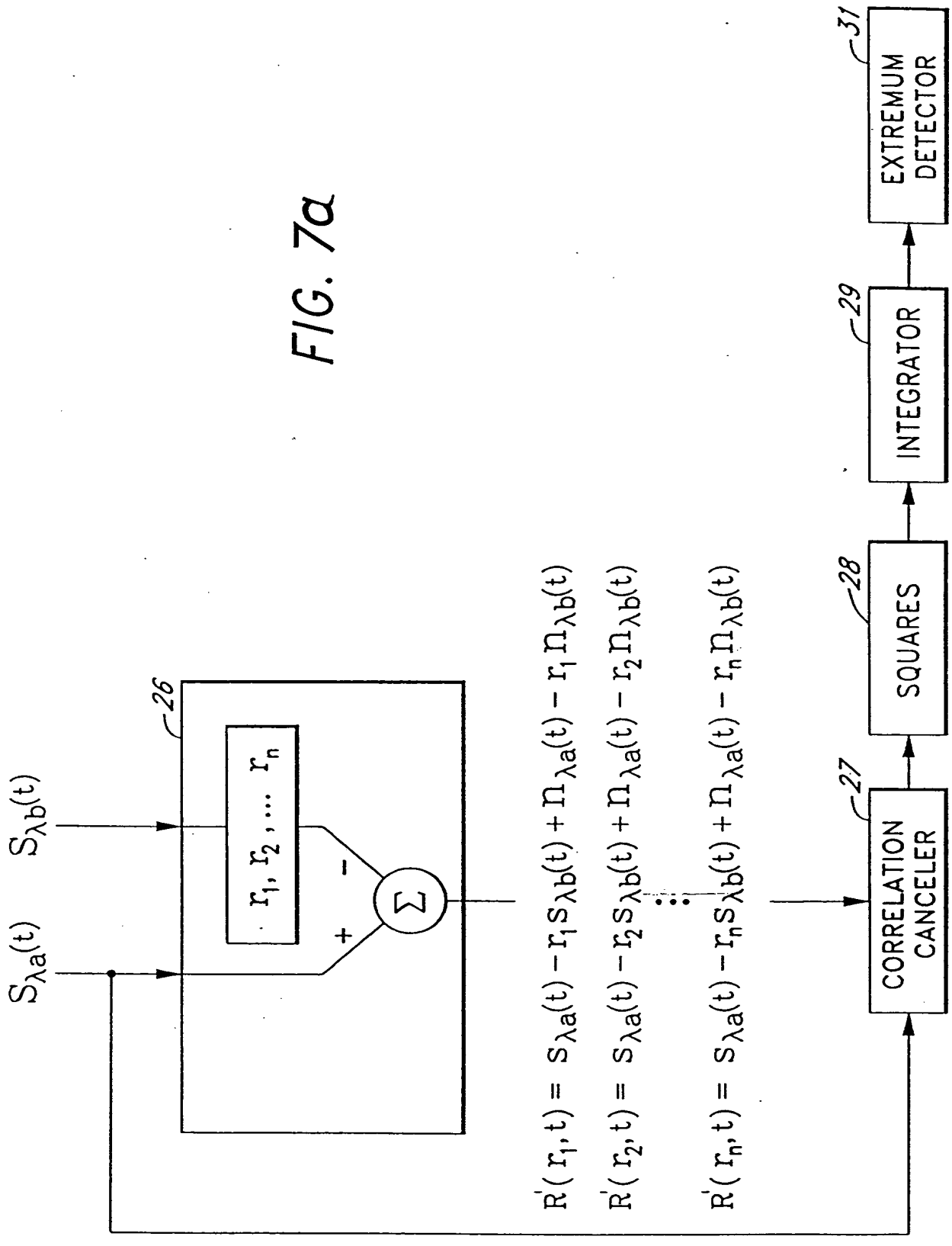

$S_{\lambda b}(t)$
$S_{\lambda a}(t)$
26
$r_1, r_2, \ldots r_n$
−
+
Σ
$R'(r_1,t) = S_{\lambda a}(t) - r_1 S_{\lambda b}(t) + n_{\lambda a}(t) - r_1 n_{\lambda b}(t)$
$R'(r_2,t) = S_{\lambda a}(t) - r_2 S_{\lambda b}(t) + n_{\lambda a}(t) - r_2 n_{\lambda b}(t)$
$R'(r_n,t) = S_{\lambda a}(t) - r_n S_{\lambda b}(t) + n_{\lambda a}(t) - r_n n_{\lambda b}(t)$
27
CORRELATION CANCELER
28
SQUARES
29
INTEGRATOR
31
EXTREMUM DETECTOR

FIG. 7b

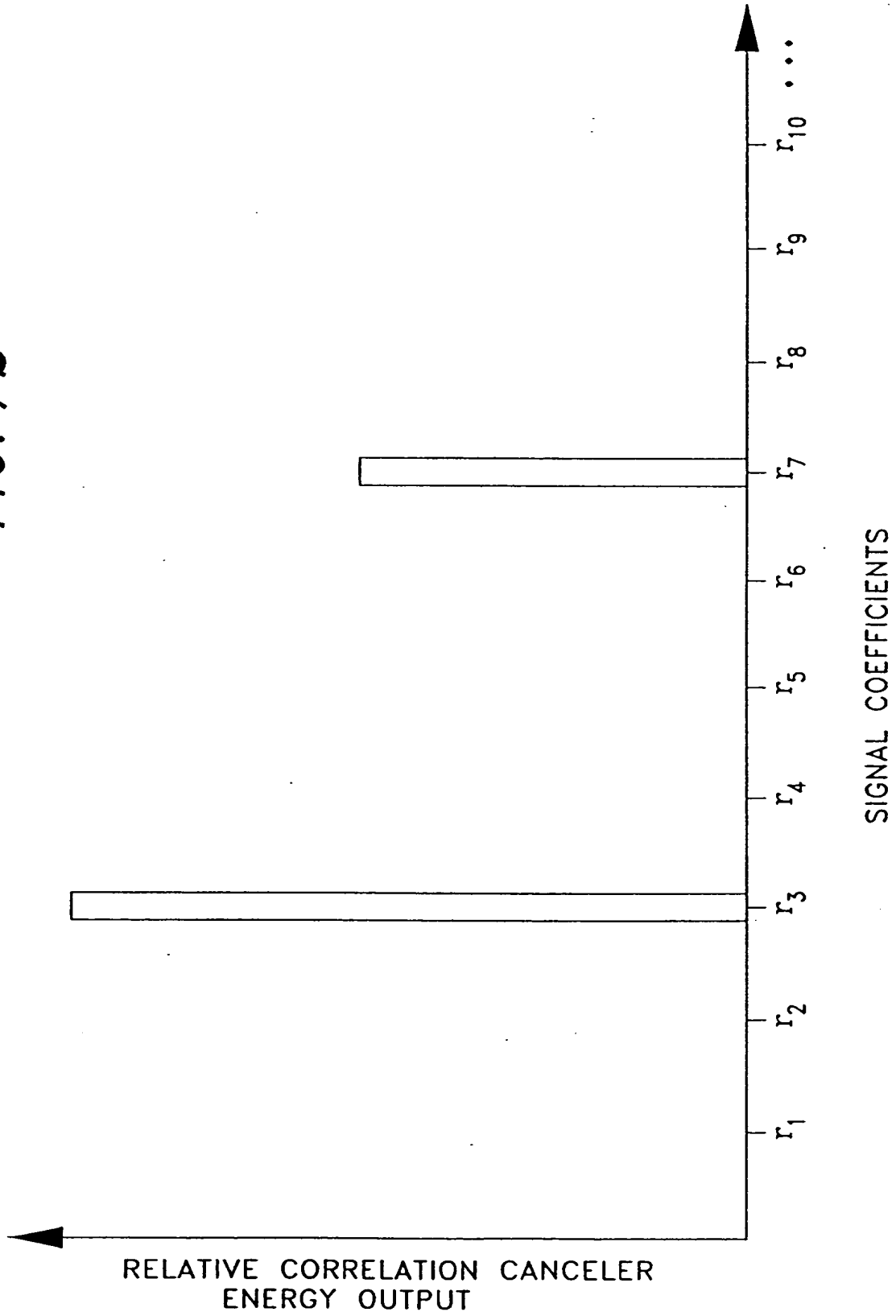
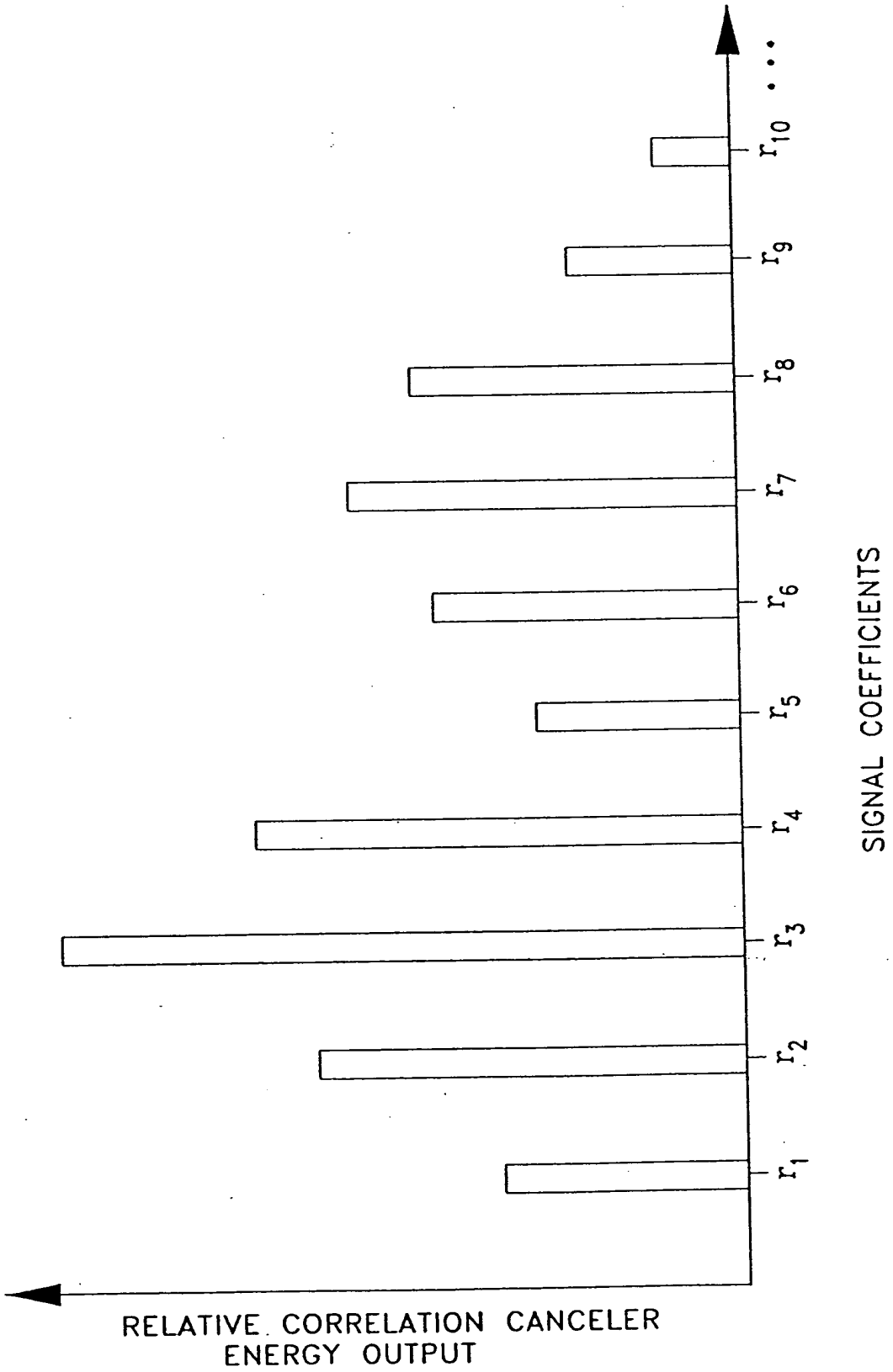

r_1
r_2
r_3
r_4
r_5
r_6
r_7
r_8
r_9
r_{10} • • •
SIGNAL COEFFICIENTS
RELATIVE CORRELATION CANCELER
ENERGY OUTPUT

FIG. 7C


r_1
r_2
r_3
r_4
r_5
r_6
r_7
r_8
r_9
r_{10} • • •
SIGNAL COEFFICIENTS
RELATIVE CORRELATION CANCELER ENERGY OUTPUT

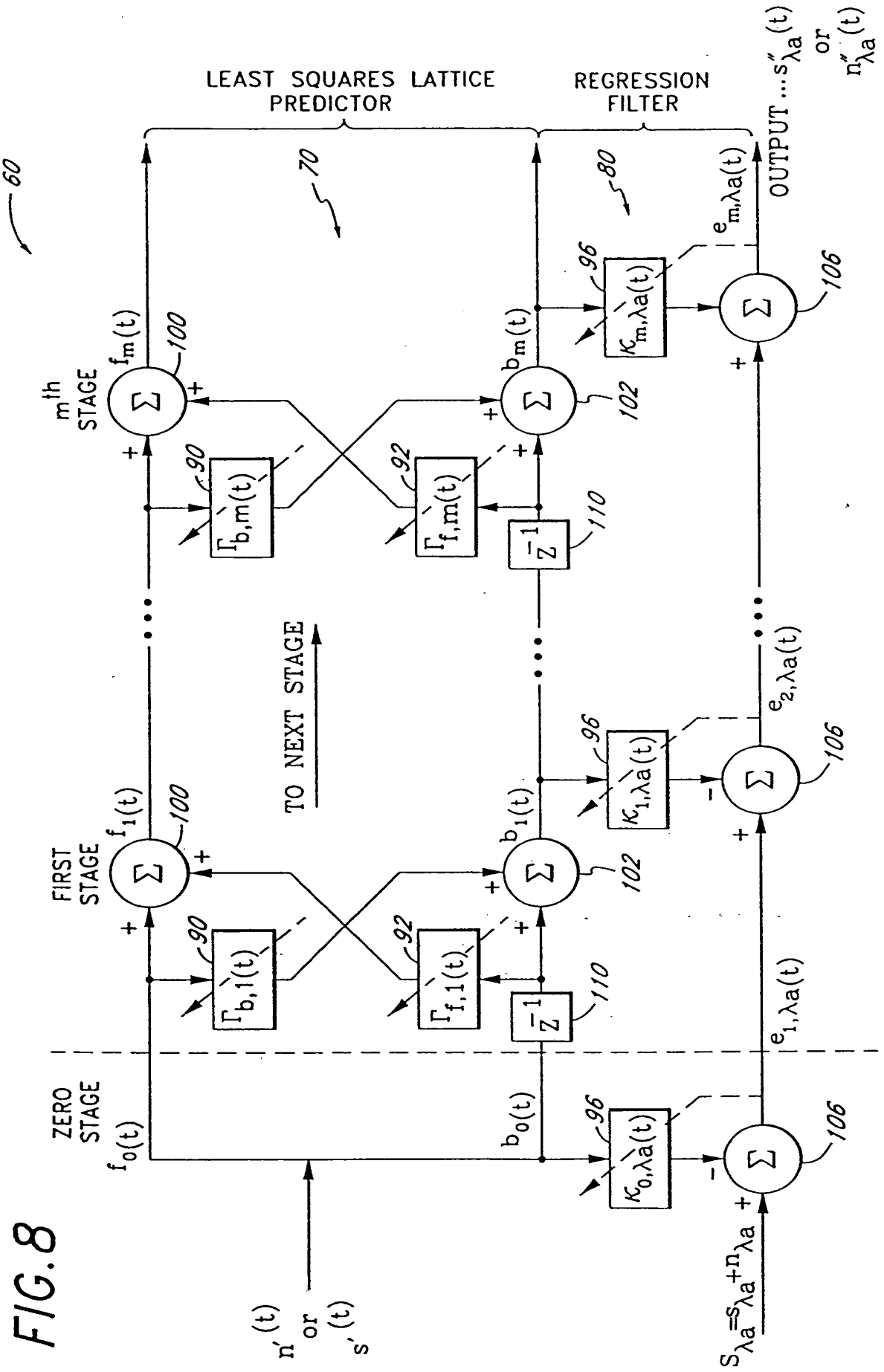

60
LEAST SQUARES LATTICE PREDICTOR
70
REGRESSION FILTER
80
OUTPUT ... $s''_{\lambda a}(t)$ or $n''_{\lambda a}(t)$
m^{th} STAGE
FIRST STAGE
ZERO STAGE
TO NEXT STAGE
$f_m(t)$
$f_1(t)$
$f_0(t)$
$b_m(t)$
$b_1(t)$
$b_0(t)$
$\Gamma_{b,m}(t)$
$\Gamma_{f,m}(t)$
$\Gamma_{b,1}(t)$
$\Gamma_{f,1}(t)$
$\kappa_{m,\lambda a}(t)$
$\kappa_{1,\lambda a}(t)$
$\kappa_{0,\lambda a}(t)$
$e_{m,\lambda a}(t)$
$e_{2,\lambda a}(t)$
$e_{1,\lambda a}(t)$
$n'(t)$ or $s'(t)$
$S_{\lambda a}=s_{\lambda a}+n_{\lambda a}$
90
92
96
100
102
106
110

FIG. 8

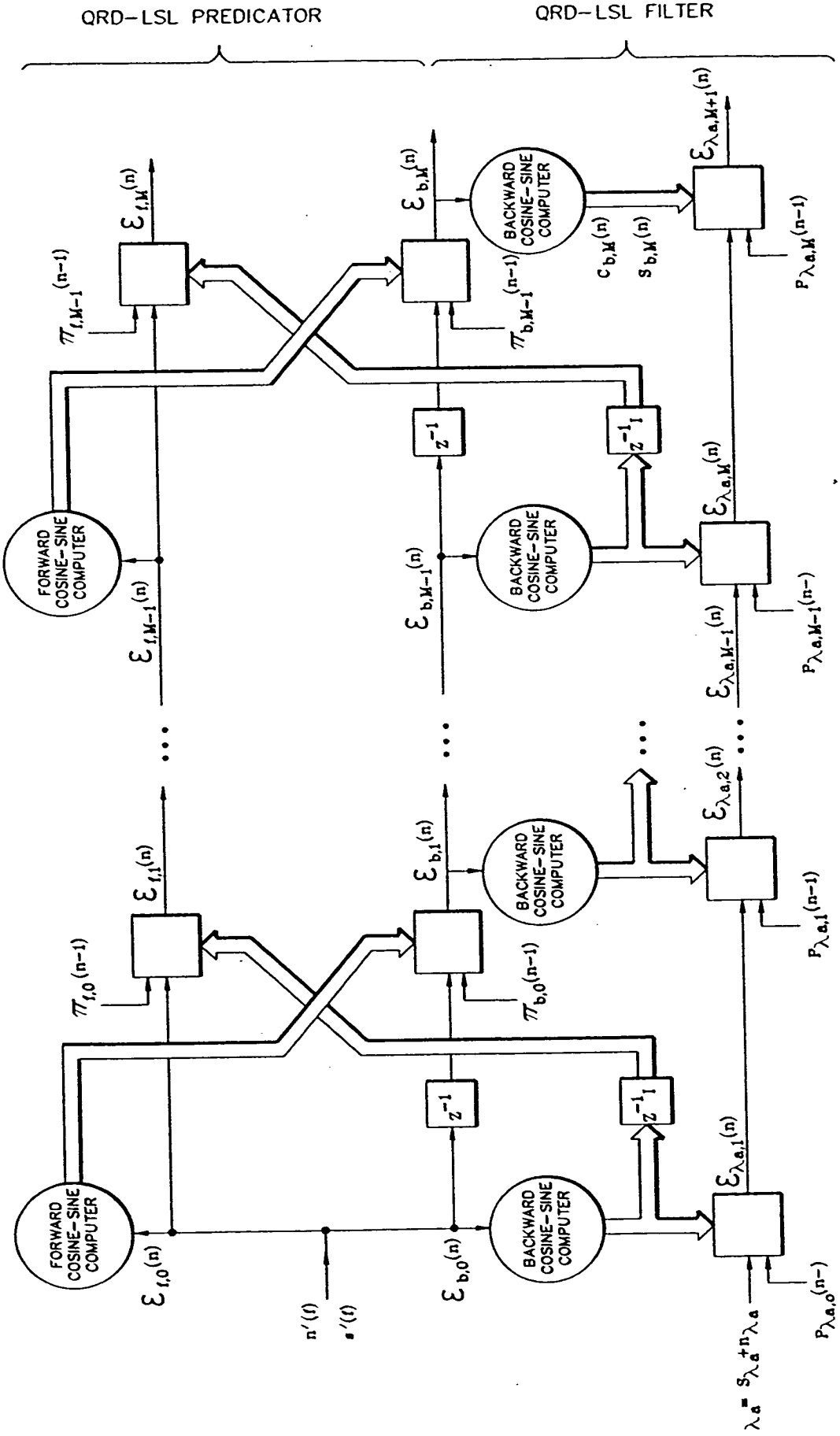

QRD-LSL PREDICATOR
QRD-LSL FILTER
FORWARD COSINE-SINE COMPUTER
BACKWARD COSINE-SINE COMPUTER
z^{-1}
$\varepsilon_{f,M}(n)$
$\varepsilon_{b,M}(n)$
$\varepsilon_{\lambda a,M+1}(n)$
$\pi_{f,M-1}(n-1)$
$\pi_{b,M-1}(n-1)$
$c_{b,M}(n)$
$s_{b,M}(n)$
$P_{\lambda a,M}(n-1)$
$\varepsilon_{f,M-1}(n)$
$\varepsilon_{b,M-1}(n)$
$\varepsilon_{\lambda a,M}(n)$
$P_{\lambda a,M-1}(n-)$
$\varepsilon_{\lambda a,M-1}(n)$
$\varepsilon_{f,1}(n)$
$\varepsilon_{b,1}(n)$
$\varepsilon_{\lambda a,2}(n)$
$P_{\lambda a,1}(n-1)$
$\pi_{f,0}(n-1)$
$\pi_{b,0}(n-1)$
$\varepsilon_{\lambda a,1}(n)$
$\varepsilon_{f,0}(n)$
$\varepsilon_{b,0}(n)$
$P_{\lambda a,0}(n-)$
$n'(l)$
$s'(l)$
$\lambda a = s_{\lambda a} + n_{\lambda a}$

FIG. 8a

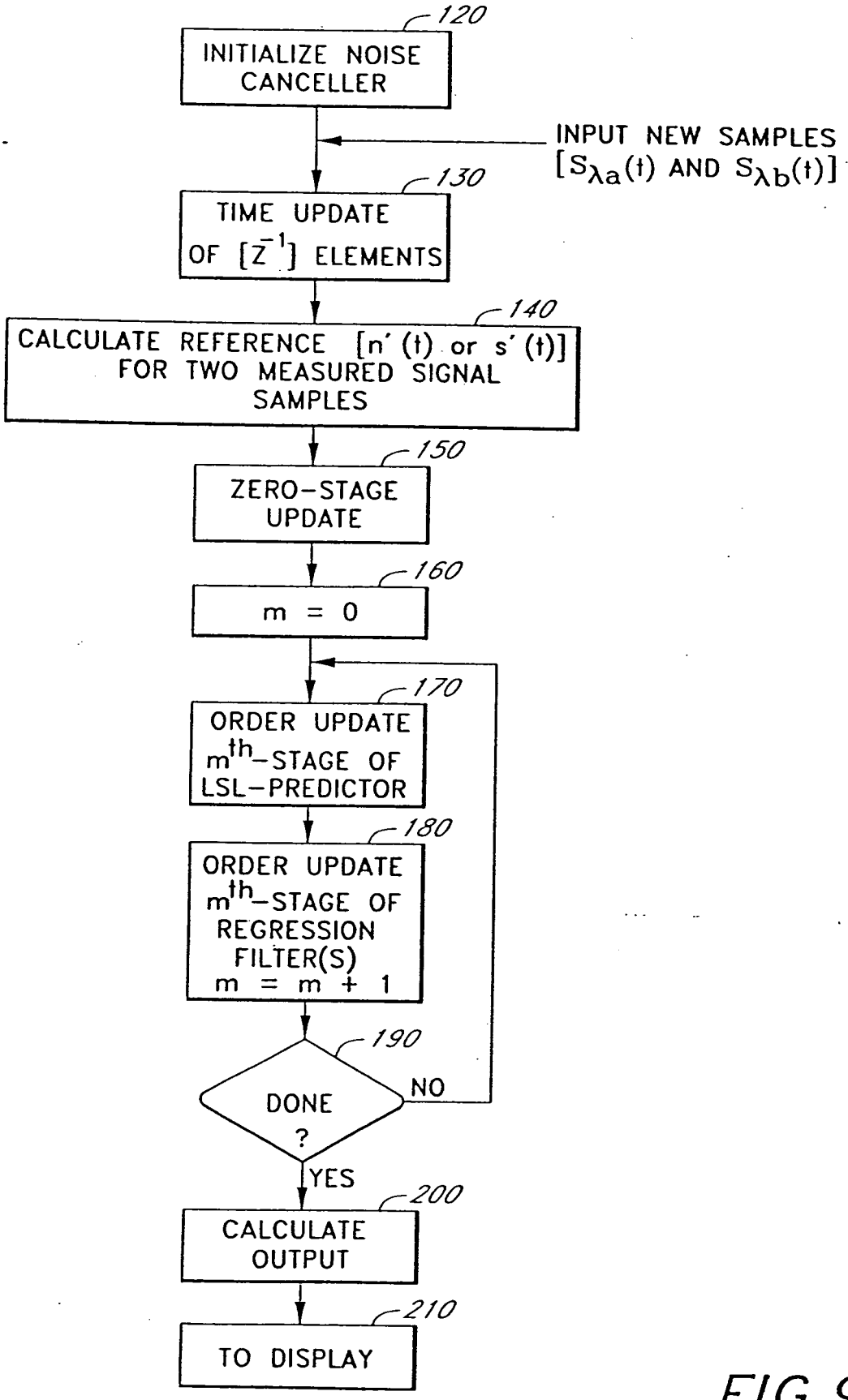

120
INITIALIZE NOISE CANCELLER
INPUT NEW SAMPLES [$S_{\lambda a}(t)$ AND $S_{\lambda b}(t)$]
130
TIME UPDATE OF [Z^{-1}] ELEMENTS
140
CALCULATE REFERENCE [n' (t) or s' (t)] FOR TWO MEASURED SIGNAL SAMPLES
150
ZERO-STAGE UPDATE
160
m = 0
170
ORDER UPDATE m^{th}-STAGE OF LSL-PREDICTOR
180
ORDER UPDATE m^{th}-STAGE OF REGRESSION FILTER(S)
m = m + 1
190
DONE ?
NO
YES
200
CALCULATE OUTPUT
210
TO DISPLAY

FIG.9

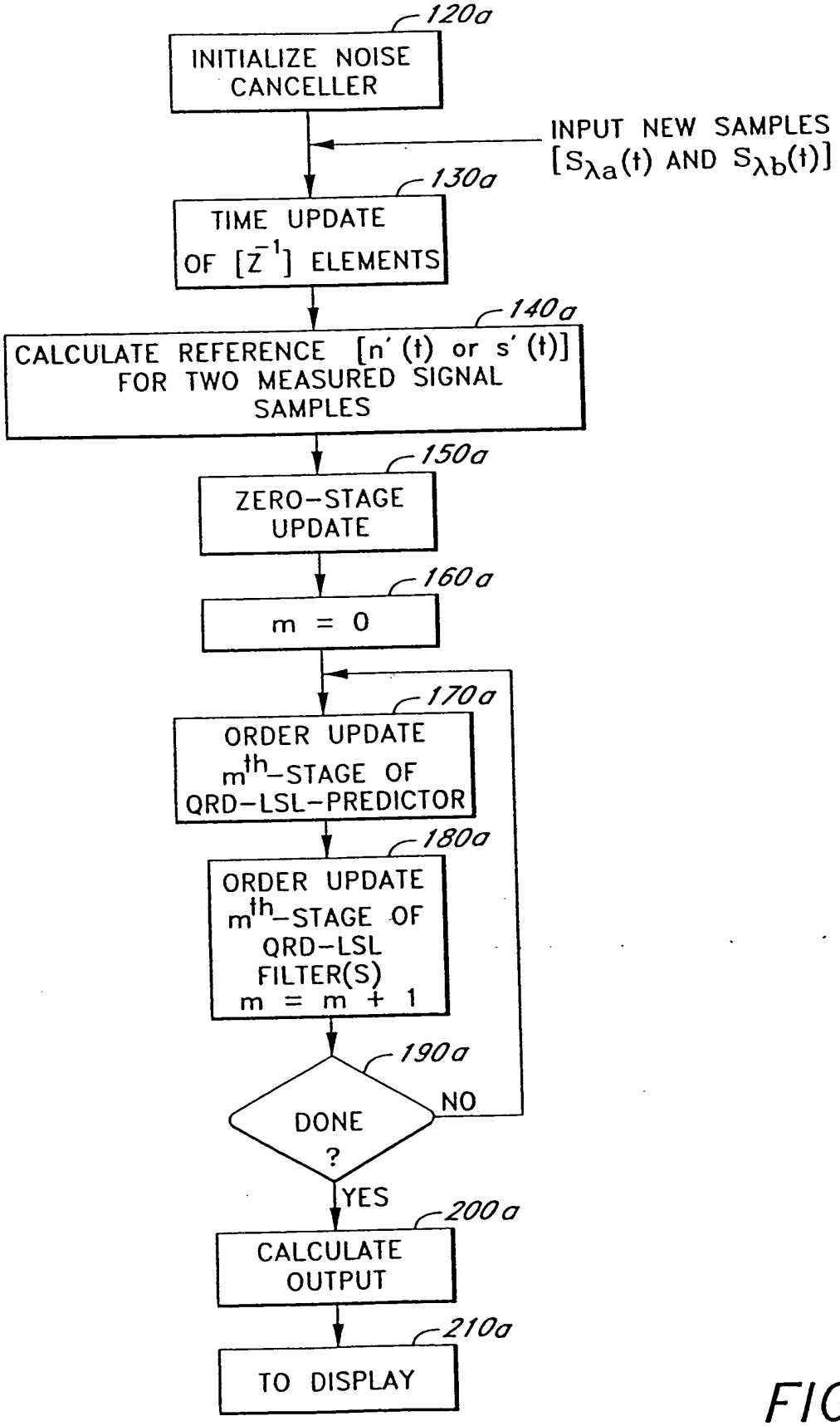

120a
INITIALIZE NOISE CANCELLER
INPUT NEW SAMPLES [$S_{\lambda a}(t)$ AND $S_{\lambda b}(t)$]
130a
TIME UPDATE OF [Z^{-1}] ELEMENTS
140a
CALCULATE REFERENCE [n' (t) or s' (t)] FOR TWO MEASURED SIGNAL SAMPLES
150a
ZERO-STAGE UPDATE
160a
m = 0
170a
ORDER UPDATE m^{th}-STAGE OF QRD-LSL-PREDICTOR
180a
ORDER UPDATE m^{th}-STAGE OF QRD-LSL FILTER(S) m = m + 1
190a
DONE ?
NO
YES
200a
CALCULATE OUTPUT
210a
TO DISPLAY

FIG.9a

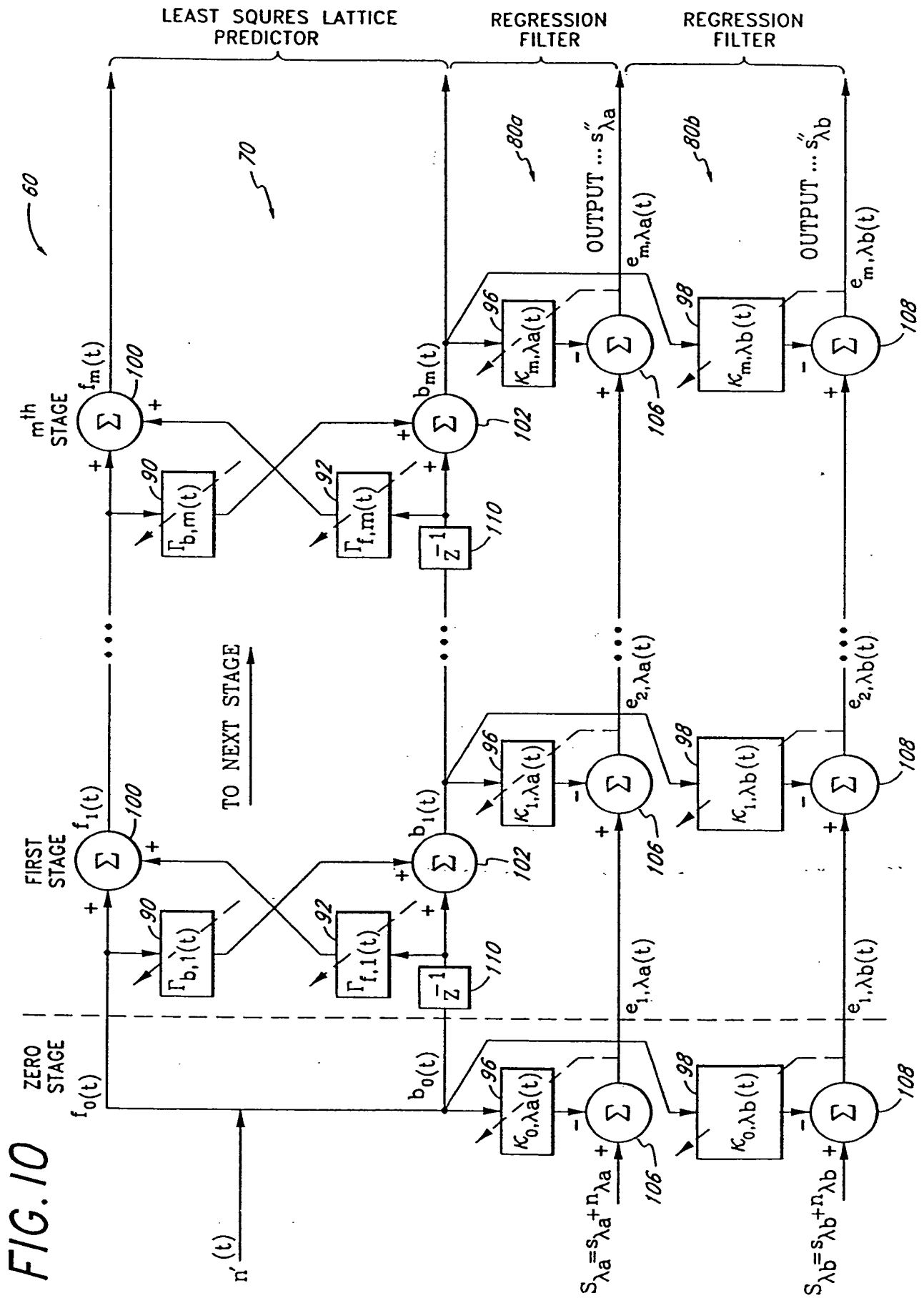

LEAST SQURES LATTICE PREDICTOR
REGRESSION FILTER
REGRESSION FILTER
60
70
80a
80b
OUTPUT ... $s''_{\lambda a}$
OUTPUT ... $s''_{\lambda b}$
m^{th} STAGE
FIRST STAGE
ZERO STAGE
TO NEXT STAGE
$f_m(t)$
$b_m(t)$
$f_1(t)$
$b_1(t)$
$f_0(t)$
$b_0(t)$
$\Gamma_{b,m}(t)$
$\Gamma_{f,m}(t)$
$\Gamma_{b,1}(t)$
$\Gamma_{f,1}(t)$
z^{-1}
$\kappa_{m,\lambda a}(t)$
$\kappa_{m,\lambda b}(t)$
$\kappa_{1,\lambda a}(t)$
$\kappa_{1,\lambda b}(t)$
$\kappa_{0,\lambda a}(t)$
$\kappa_{0,\lambda b}(t)$
$e_{m,\lambda a}(t)$
$e_{m,\lambda b}(t)$
$e_{2,\lambda a}(t)$
$e_{2,\lambda b}(t)$
$e_{1,\lambda a}(t)$
$e_{1,\lambda b}(t)$
90
92
96
98
100
102
106
108
110
$n'(t)$
$s_{\lambda a}=s_{\lambda a}+n_{\lambda a}$
$s_{\lambda b}=s_{\lambda b}+n_{\lambda b}$

FIG. 10

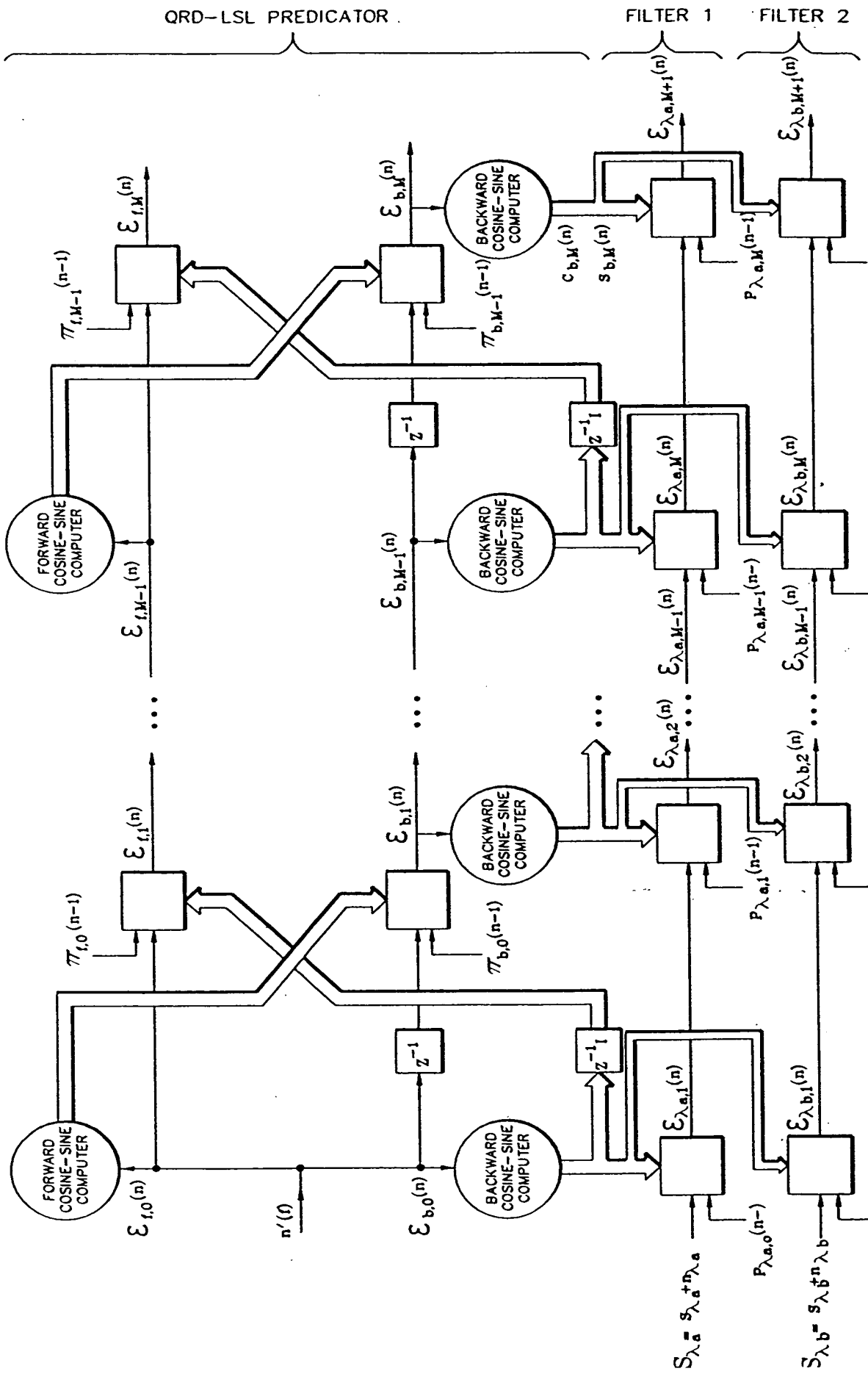

QRD–LSL PREDICATOR
FILTER 1
FILTER 2
FORWARD COSINE–SINE COMPUTER
BACKWARD COSINE–SINE COMPUTER
z^{-1}
$\varepsilon_{1,M}^{(n)}$
$\varepsilon_{b,M}^{(n)}$
$\varepsilon_{\lambda a,M+1}^{(n)}$
$\varepsilon_{\lambda b,M+1}^{(n)}$
$\pi_{1,M-1}^{(n-1)}$
$\pi_{b,M-1}^{(n-1)}$
$c_{b,M}^{(n)}$
$s_{b,M}^{(n)}$
$P_{\lambda a,M}^{(n-1)}$
$P_{\lambda b,M}^{(n-1)}$
$\varepsilon_{1,M-1}^{(n)}$
$\varepsilon_{b,M-1}^{(n)}$
$\varepsilon_{\lambda a,M}^{(n)}$
$\varepsilon_{\lambda b,M}^{(n)}$
$P_{\lambda a,M-1}^{(n-)}$
$P_{\lambda b,M-1}^{(n-)}$
$\varepsilon_{\lambda a,M-1}^{(n)}$
$\varepsilon_{\lambda b,M-1}^{(n)}$
$\varepsilon_{\lambda a,2}^{(n)}$
$\varepsilon_{\lambda b,2}^{(n)}$
$\varepsilon_{1,1}^{(n)}$
$\varepsilon_{b,1}^{(n)}$
$\pi_{1,0}^{(n-1)}$
$\pi_{b,0}^{(n-1)}$
$P_{\lambda a,1}^{(n-1)}$
$P_{\lambda b,1}^{(n-1)}$
$\varepsilon_{\lambda a,1}^{(n)}$
$\varepsilon_{\lambda b,1}^{(n)}$
$\varepsilon_{1,0}^{(n)}$
$n'(t)$
$\varepsilon_{b,0}^{(n)}$
$P_{\lambda a,0}^{(n-)}$
$P_{\lambda b,0}^{(n-1)}$
$S_{\lambda a} = s_{\lambda a} + n_{\lambda a}$
$S_{\lambda b} = s_{\lambda b} + n_{\lambda b}$

FIG. 10a

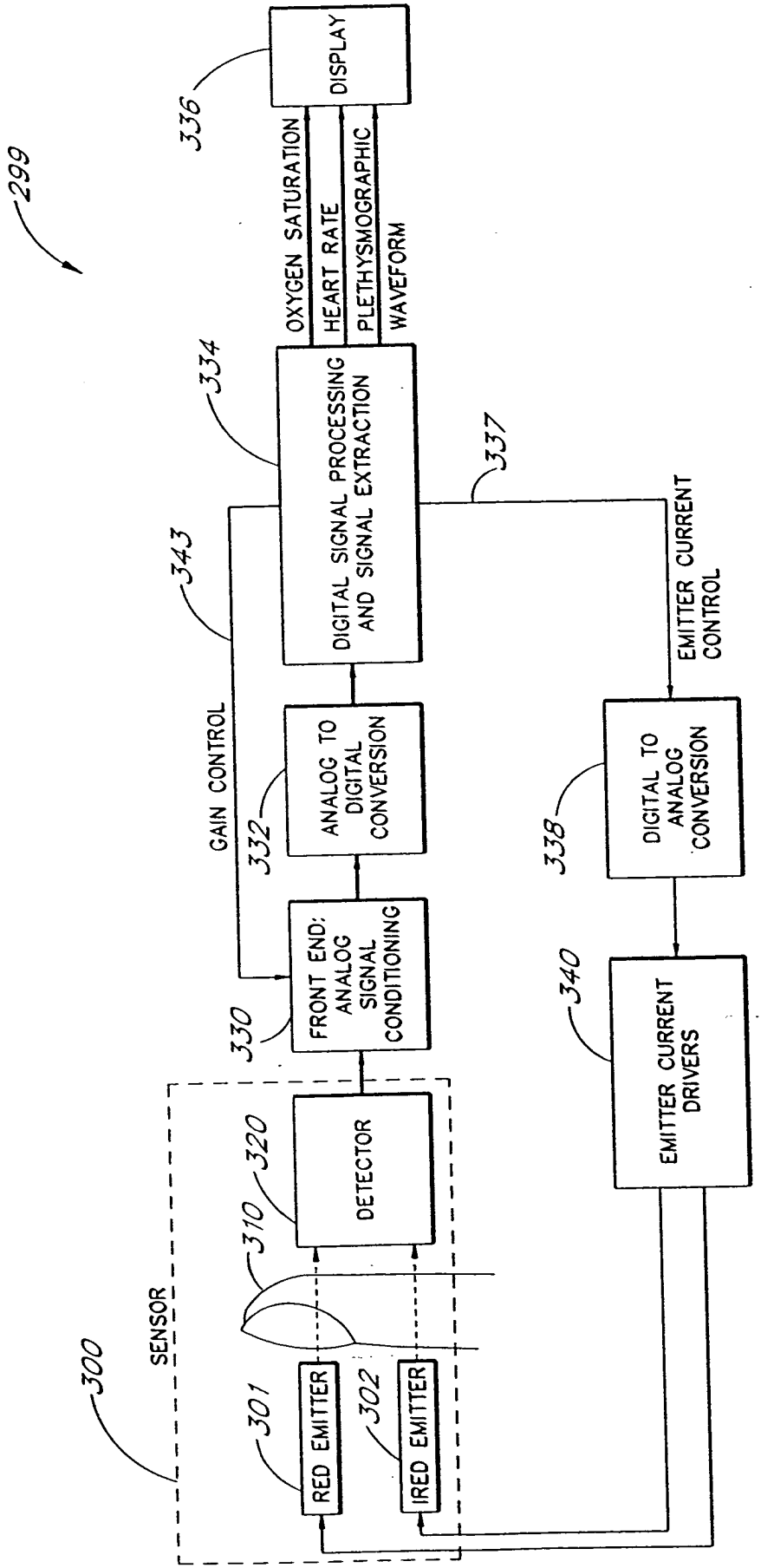

299
300
SENSOR
301
RED EMITTER
302
IRED EMITTER
310
320
DETECTOR
330
FRONT END: ANALOG SIGNAL CONDITIONING
332
ANALOG TO DIGITAL CONVERSION
334
DIGITAL SIGNAL PROCESSING AND SIGNAL EXTRACTION
336
DISPLAY
OXYGEN SATURATION
HEART RATE
PLETHYSMOGRAPHIC WAVEFORM
337
338
DIGITAL TO ANALOG CONVERSION
340
EMITTER CURRENT DRIVERS
343
GAIN CONTROL
EMITTER CURRENT CONTROL

FIG. 11

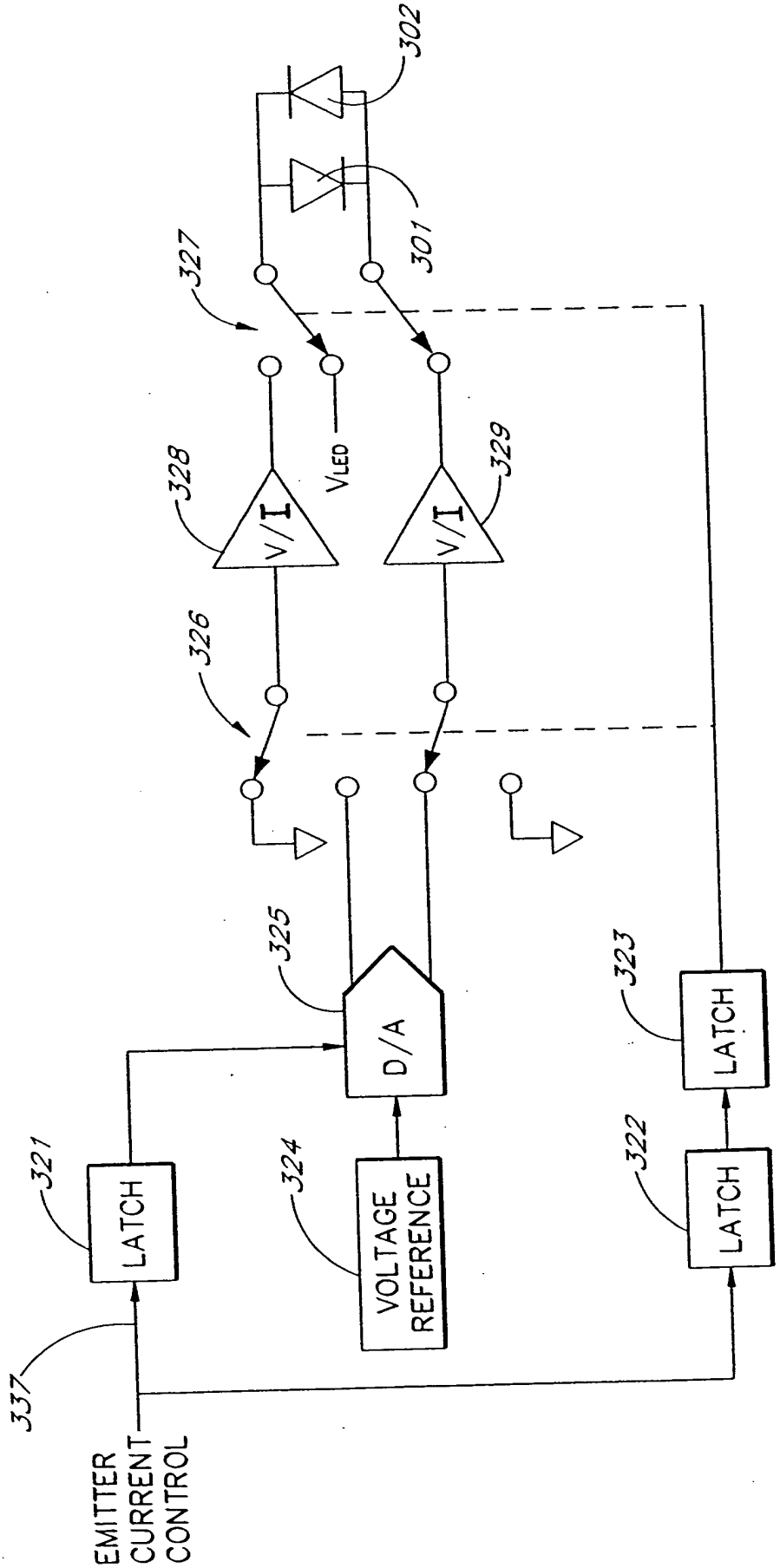

302
301
327
328
V/I
VLED
329
V/I
326
325
D/A
323
LATCH
321
LATCH
324
VOLTAGE REFERENCE
322
LATCH
337
EMITTER CURRENT CONTROL

FIG. 11A

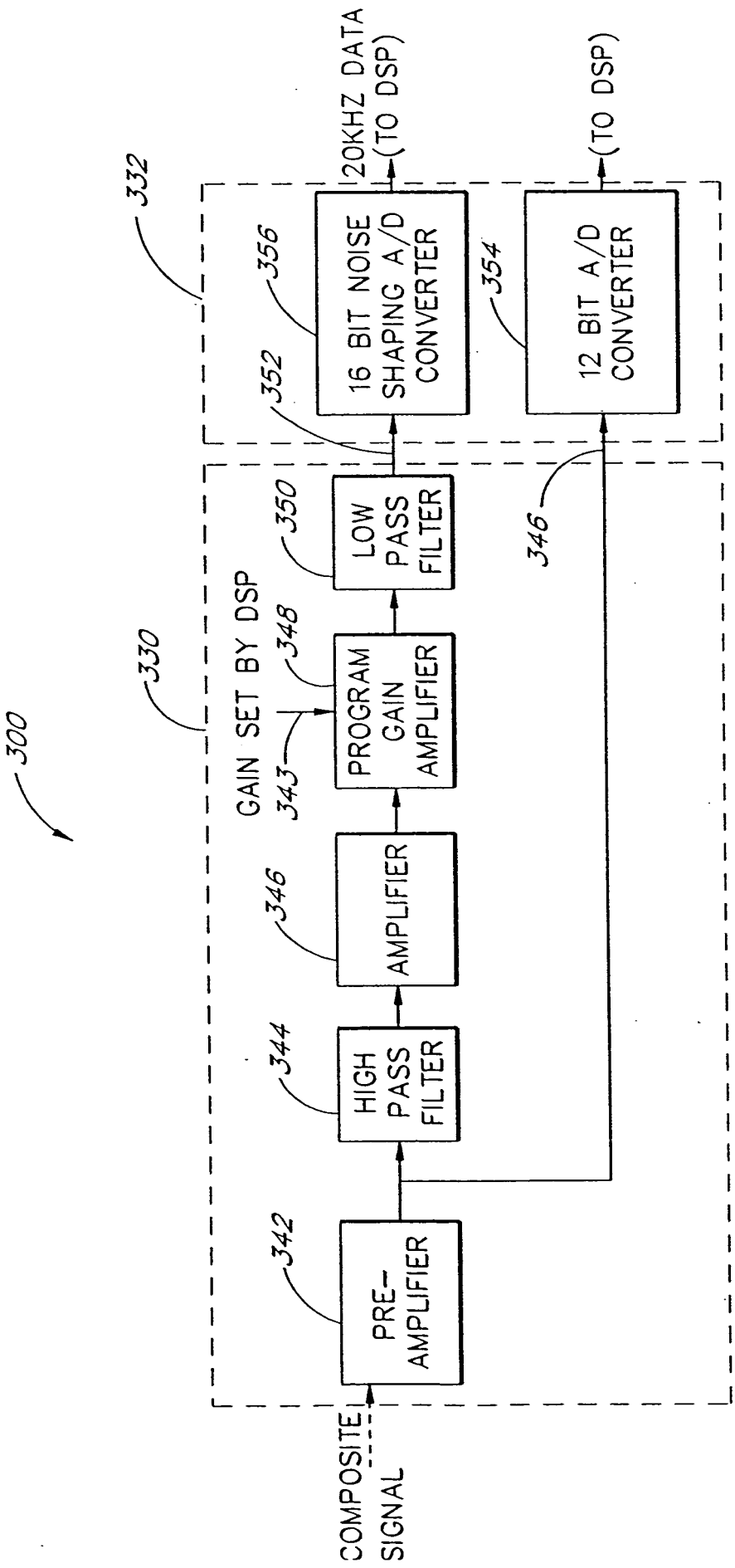

300
330
GAIN SET BY DSP
332
COMPOSITE SIGNAL
PRE-AMPLIFIER
342
HIGH PASS FILTER
344
AMPLIFIER
346
PROGRAM GAIN AMPLIFIER
348
343
LOW PASS FILTER
350
352
16 BIT NOISE SHAPING A/D CONVERTER
356
20KHZ DATA (TO DSP)
12 BIT A/D CONVERTER
354
(TO DSP)
346

FIG. 12

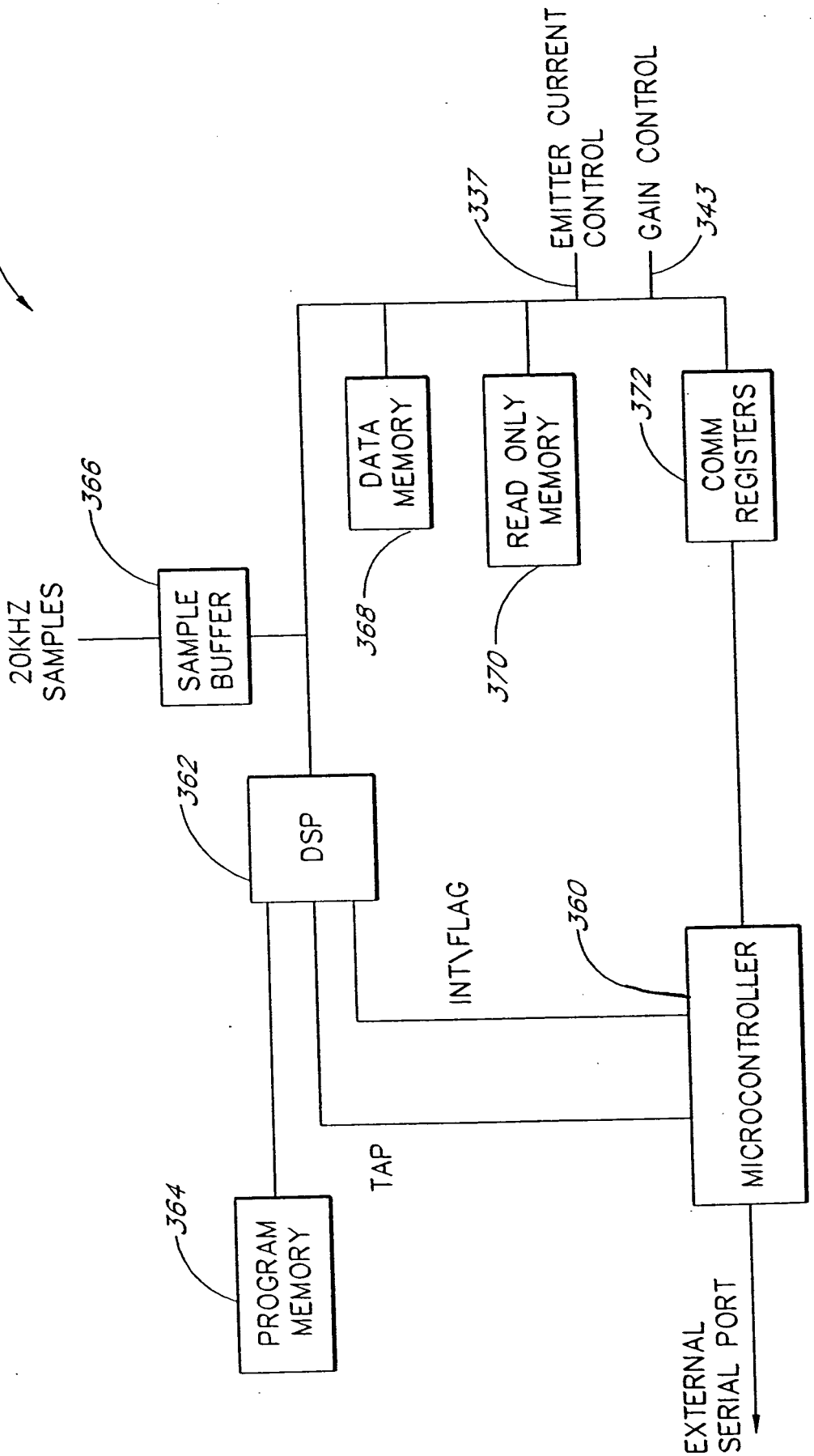

334
337
EMITTER CURRENT CONTROL
343
GAIN CONTROL
366
20KHZ SAMPLES
SAMPLE BUFFER
DATA MEMORY
368
READ ONLY MEMORY
370
372
COMM REGISTERS
362
DSP
INT\FLAG
360
MICROCONTROLLER
TAP
364
PROGRAM MEMORY
EXTERNAL SERIAL PORT

FIG. 13

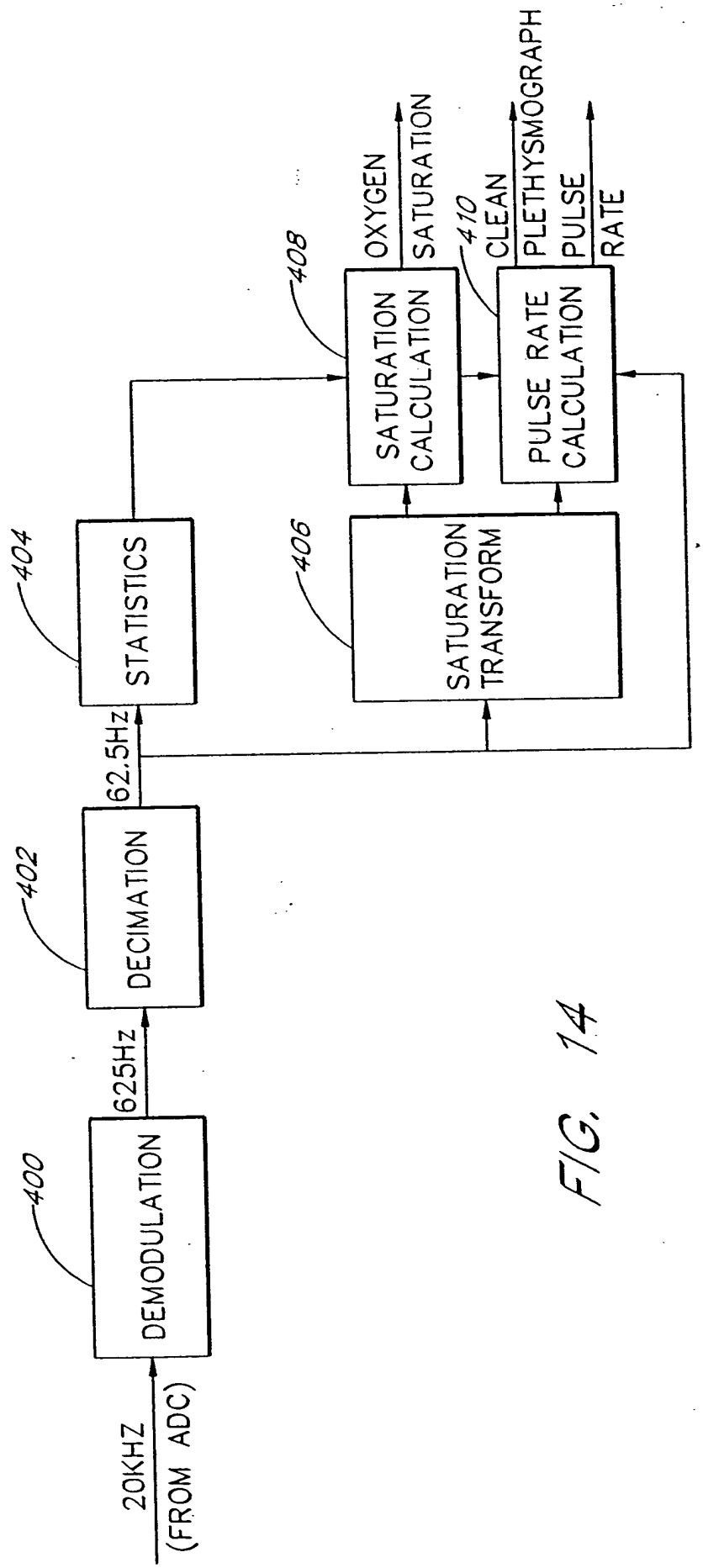

20KHZ
(FROM ADC)
400
DEMODULATION
625Hz
402
DECIMATION
62.5Hz
404
STATISTICS
406
SATURATION
TRANSFORM
408
SATURATION
CALCULATION
OXYGEN
SATURATION
410
PULSE RATE
CALCULATION
CLEAN
PLETHYSMOGRAPH
PULSE
RATE

FIG. 14

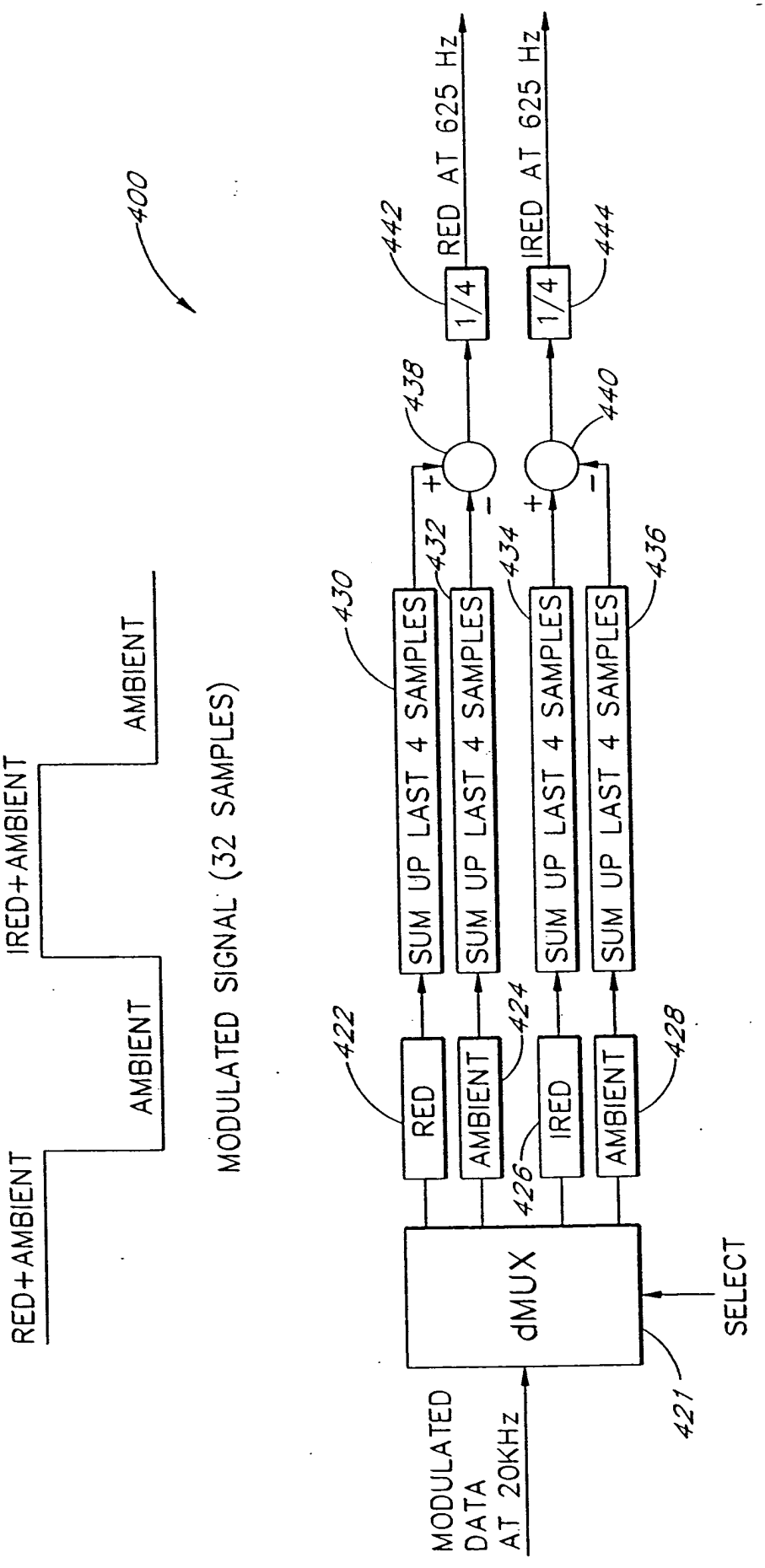

400
RED+AMBIENT
AMBIENT
IRED+AMBIENT
AMBIENT
MODULATED SIGNAL (32 SAMPLES)
MODULATED DATA AT 20KHz
dMUX
SELECT
421
RED
AMBIENT
IRED
AMBIENT
422
424
426
428
SUM UP LAST 4 SAMPLES
SUM UP LAST 4 SAMPLES
SUM UP LAST 4 SAMPLES
SUM UP LAST 4 SAMPLES
430
432
434
436
438
440
1/4
1/4
442
444
RED AT 625 Hz
IRED AT 625 Hz

FIG. 15

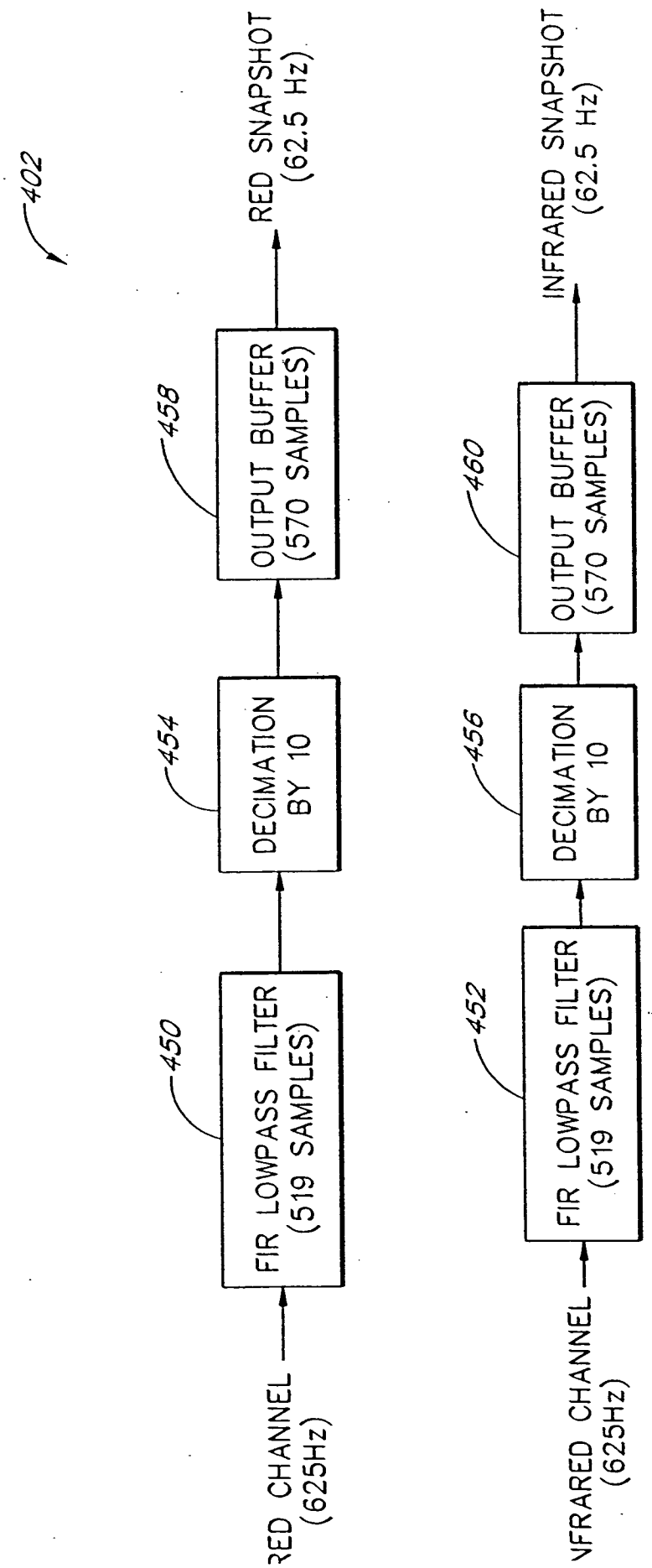

402
RED CHANNEL (625Hz)
INFRARED CHANNEL (625Hz)
450
FIR LOWPASS FILTER (519 SAMPLES)
452
FIR LOWPASS FILTER (519 SAMPLES)
454
DECIMATION BY 10
456
DECIMATION BY 10
458
OUTPUT BUFFER (570 SAMPLES)
460
OUTPUT BUFFER (570 SAMPLES)
RED SNAPSHOT (62.5 Hz)
INFRARED SNAPSHOT (62.5 Hz)

FIG. 16

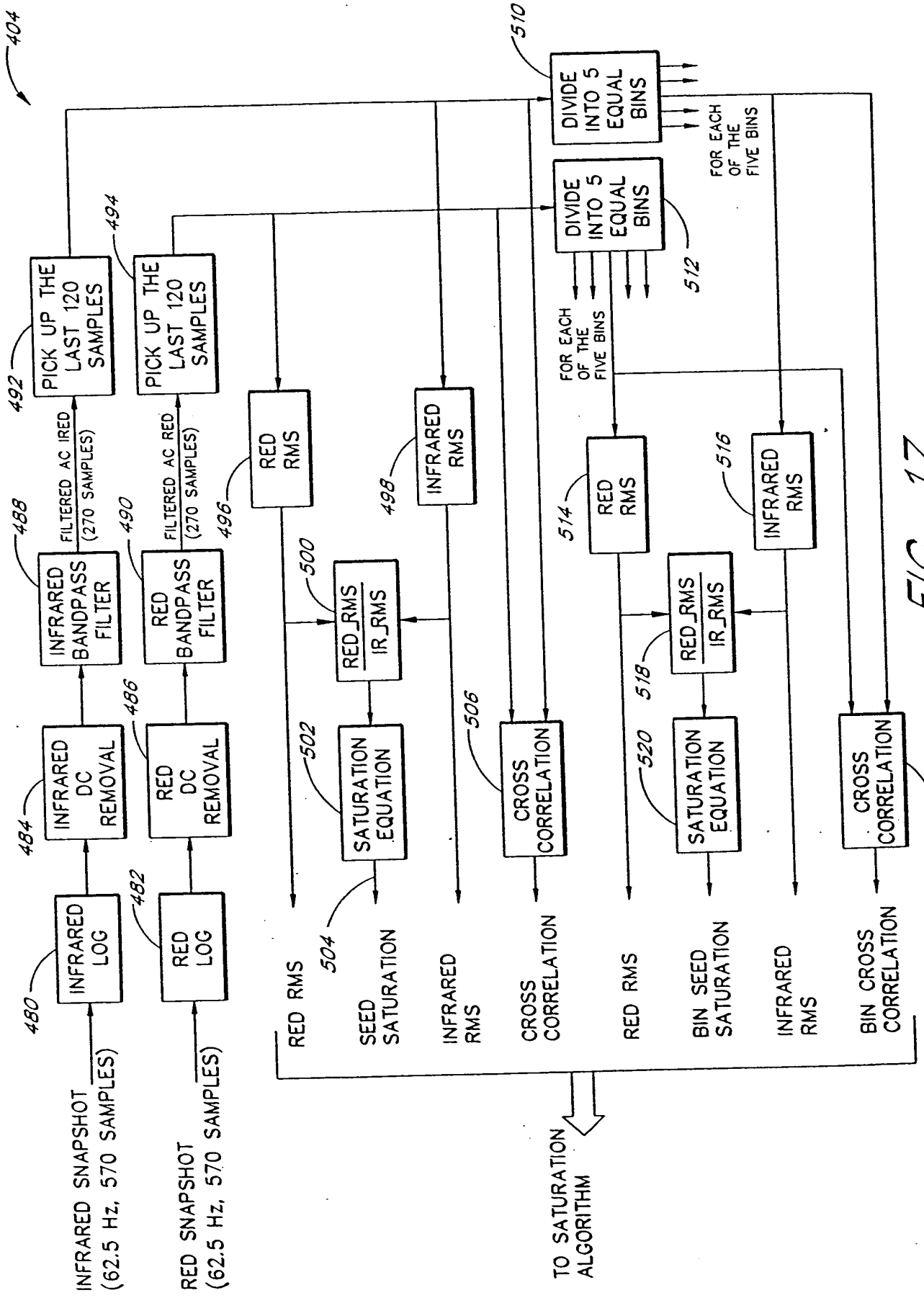

404
INFRARED SNAPSHOT (62.5 Hz, 570 SAMPLES)
RED SNAPSHOT (62.5 Hz, 570 SAMPLES)
480
INFRARED LOG
482
RED LOG
484
INFRARED DC REMOVAL
486
RED DC REMOVAL
488
INFRARED BANDPASS FILTER
FILTERED AC IRED (270 SAMPLES)
490
RED BANDPASS FILTER
FILTERED AC RED (270 SAMPLES)
492
PICK UP THE LAST 120 SAMPLES
494
PICK UP THE LAST 120 SAMPLES
496
RED RMS
498
INFRARED RMS
500
RED_RMS / IR_RMS
502
SATURATION EQUATION
504
SEED SATURATION
506
CROSS CORRELATION
510
DIVIDE INTO 5 EQUAL BINS
512
DIVIDE INTO 5 EQUAL BINS
FOR EACH OF THE FIVE BINS
FOR EACH OF THE FIVE BINS
514
RED RMS
516
INFRARED RMS
518
RED_RMS / IR_RMS
520
SATURATION EQUATION
522
CROSS CORRELATION
RED RMS
INFRARED RMS
CROSS CORRELATION
RED RMS
BIN SEED SATURATION
INFRARED RMS
BIN CROSS CORRELATION
TO SATURATION ALGORITHM

FIG. 17

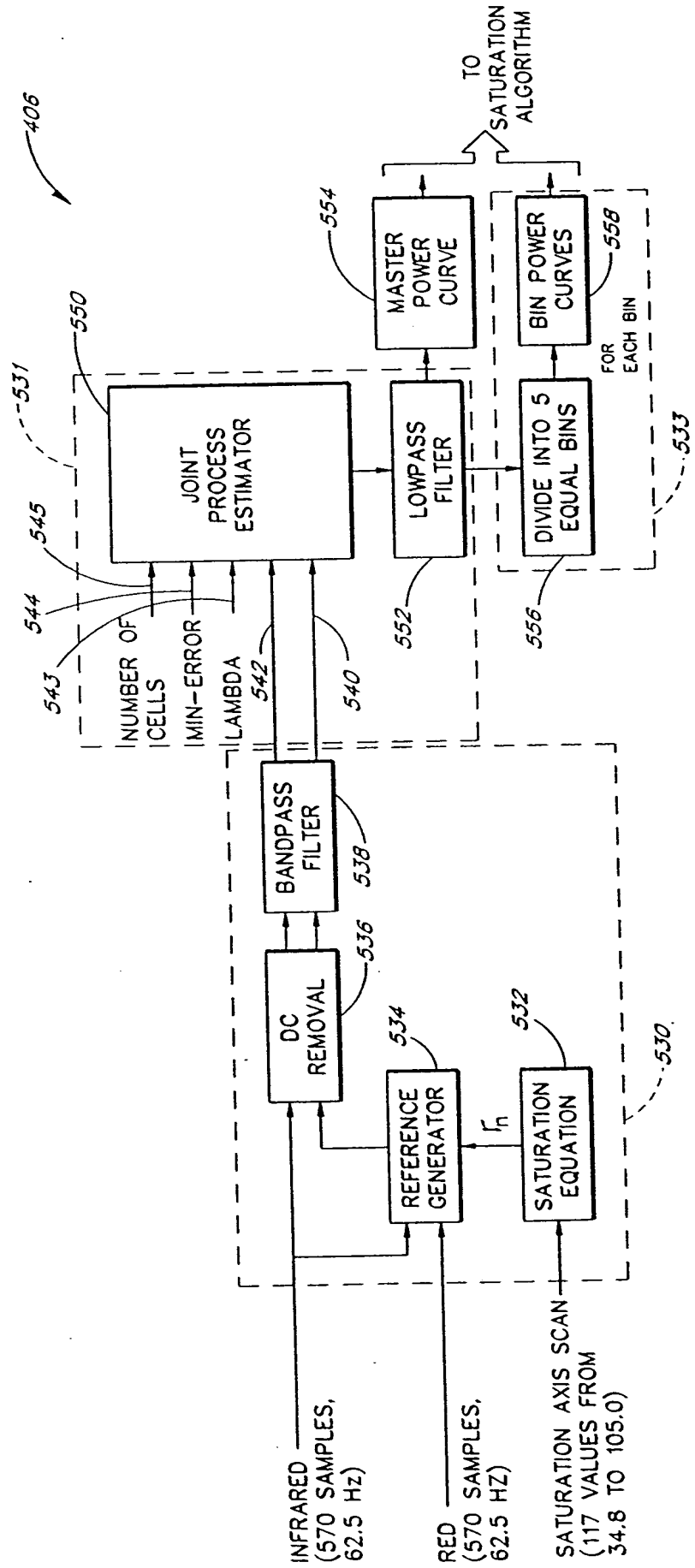

406
TO SATURATION ALGORITHM
554
MASTER POWER CURVE
558
BIN POWER CURVES
FOR EACH BIN
550
531
JOINT PROCESS ESTIMATOR
LOWPASS FILTER
DIVIDE INTO 5 EQUAL BINS
533
545
544
543
NUMBER OF CELLS
MIN-ERROR
LAMBDA
542
540
552
556
BANDPASS FILTER
538
536
DC REMOVAL
534
REFERENCE GENERATOR
r_n
532
SATURATION EQUATION
530
INFRARED (570 SAMPLES, 62.5 Hz)
RED (570 SAMPLES, 62.5 HZ)
SATURATION AXIS SCAN (117 VALUES FROM 34.8 TO 105.0)

FIG. 18

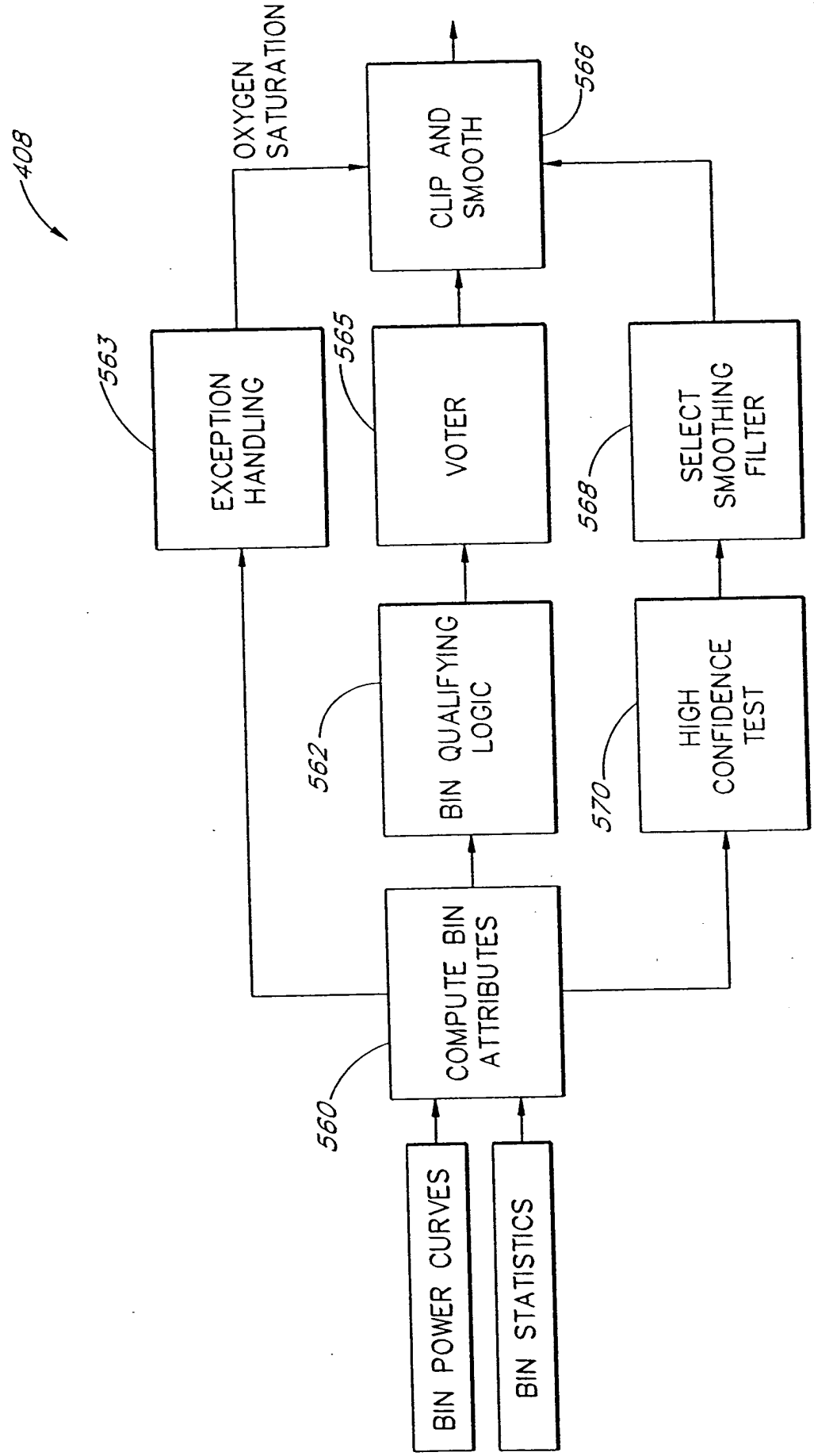

408
OXYGEN SATURATION
CLIP AND SMOOTH
566
563
EXCEPTION HANDLING
565
VOTER
568
SELECT SMOOTHING FILTER
562
BIN QUALIFYING LOGIC
570
HIGH CONFIDENCE TEST
560
COMPUTE BIN ATTRIBUTES
BIN POWER CURVES
BIN STATISTICS

FIG. 19

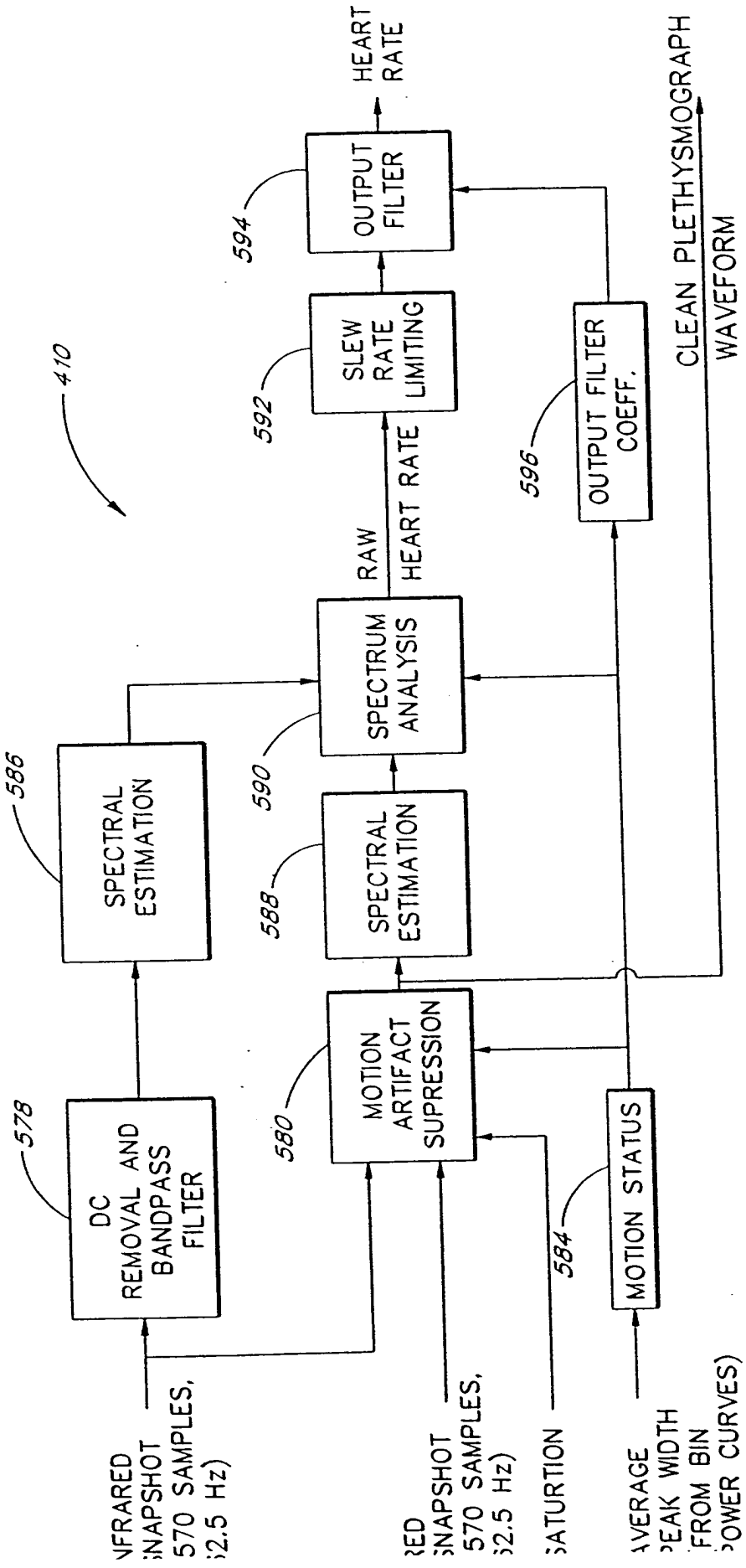

410
578
DC REMOVAL AND BANDPASS FILTER
586
SPECTRAL ESTIMATION
580
MOTION ARTIFACT SUPRESSION
588
SPECTRAL ESTIMATION
590
SPECTRUM ANALYSIS
592
SLEW RATE LIMITING
594
OUTPUT FILTER
HEART RATE
RAW HEART RATE
584
MOTION STATUS
596
OUTPUT FILTER COEFF.
CLEAN PLETHYSMOGRAPH WAVEFORM
VFRARED
SNAPSHOT
570 SAMPLES,
62.5 Hz)
RED
SNAPSHOT
570 SAMPLES,
62.5 Hz)
SATURTION
AVERAGE
PEAK WIDTH
FROM BIN
POWER CURVES)

FIG. 20

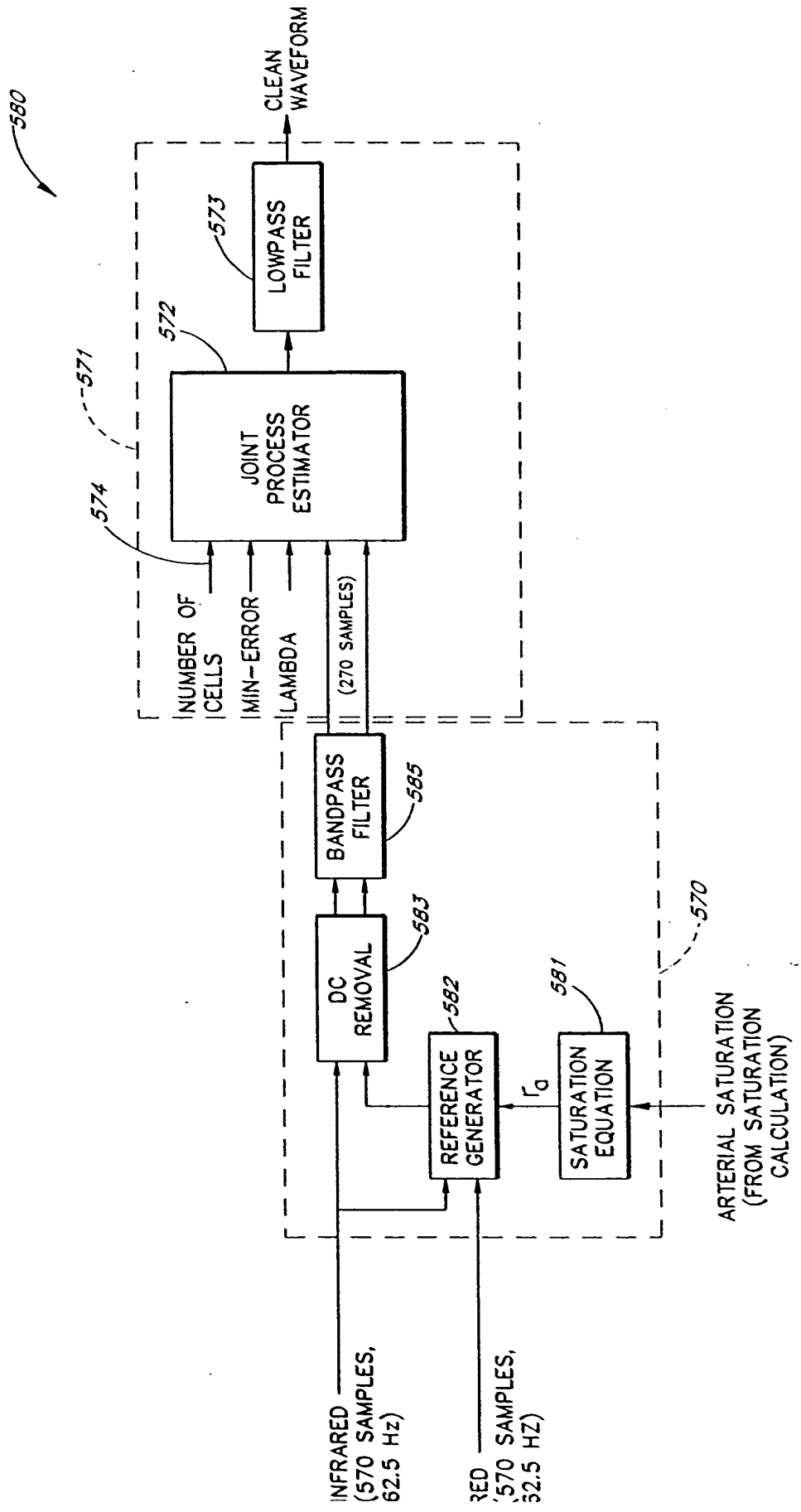

580
CLEAN WAVEFORM
573
LOWPASS FILTER
572
571
JOINT PROCESS ESTIMATOR
574
NUMBER OF CELLS
MIN-ERROR
LAMBDA
(270 SAMPLES)
BANDPASS FILTER
585
DC REMOVAL
583
582
REFERENCE GENERATOR
r_d
581
SATURATION EQUATION
570
ARTERIAL SATURATION (FROM SATURATION CALCULATION)
INFRARED (570 SAMPLES, 62.5 Hz)
RED (570 SAMPLES, 62.5 HZ)

FIG. 21

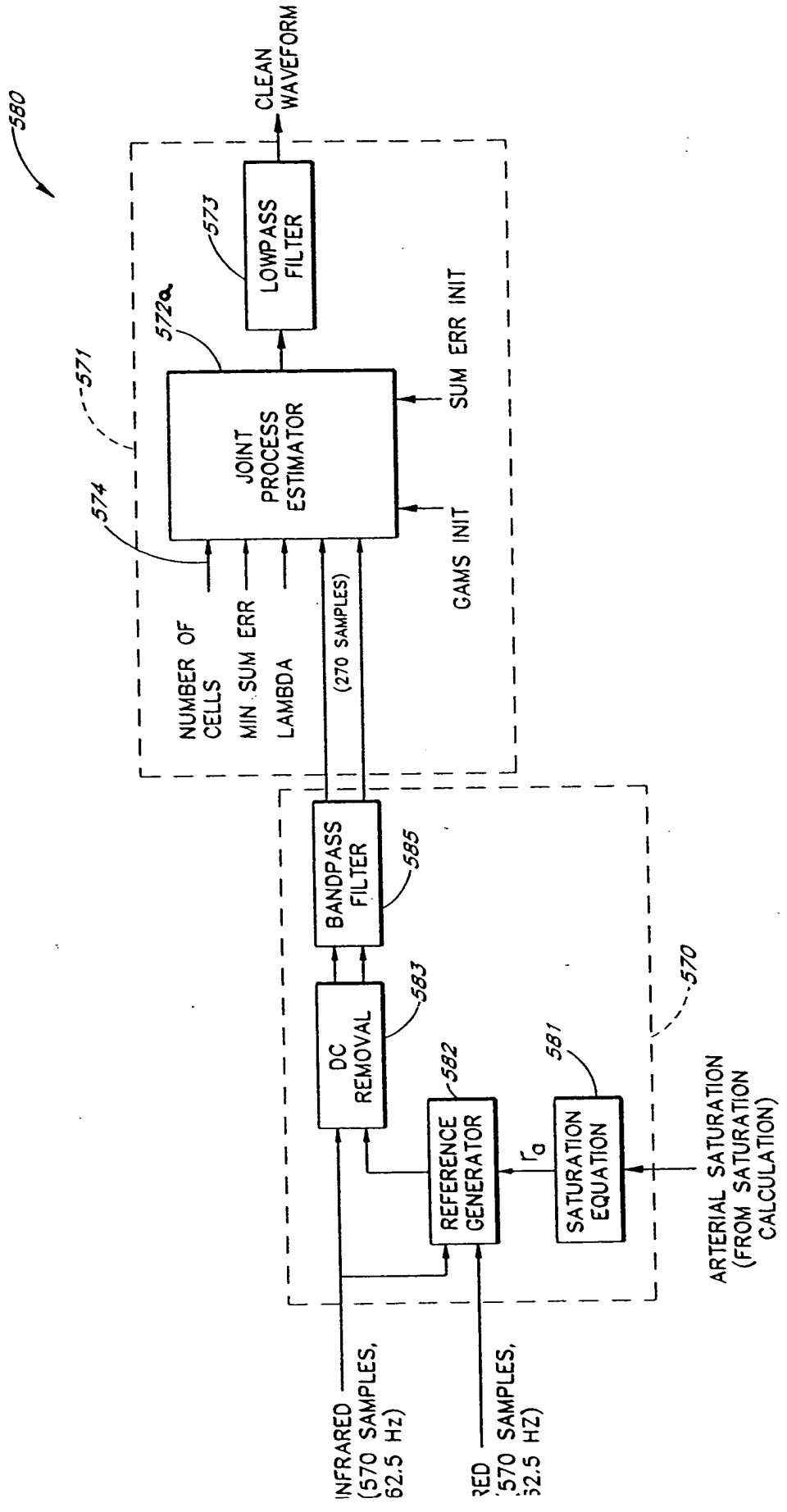
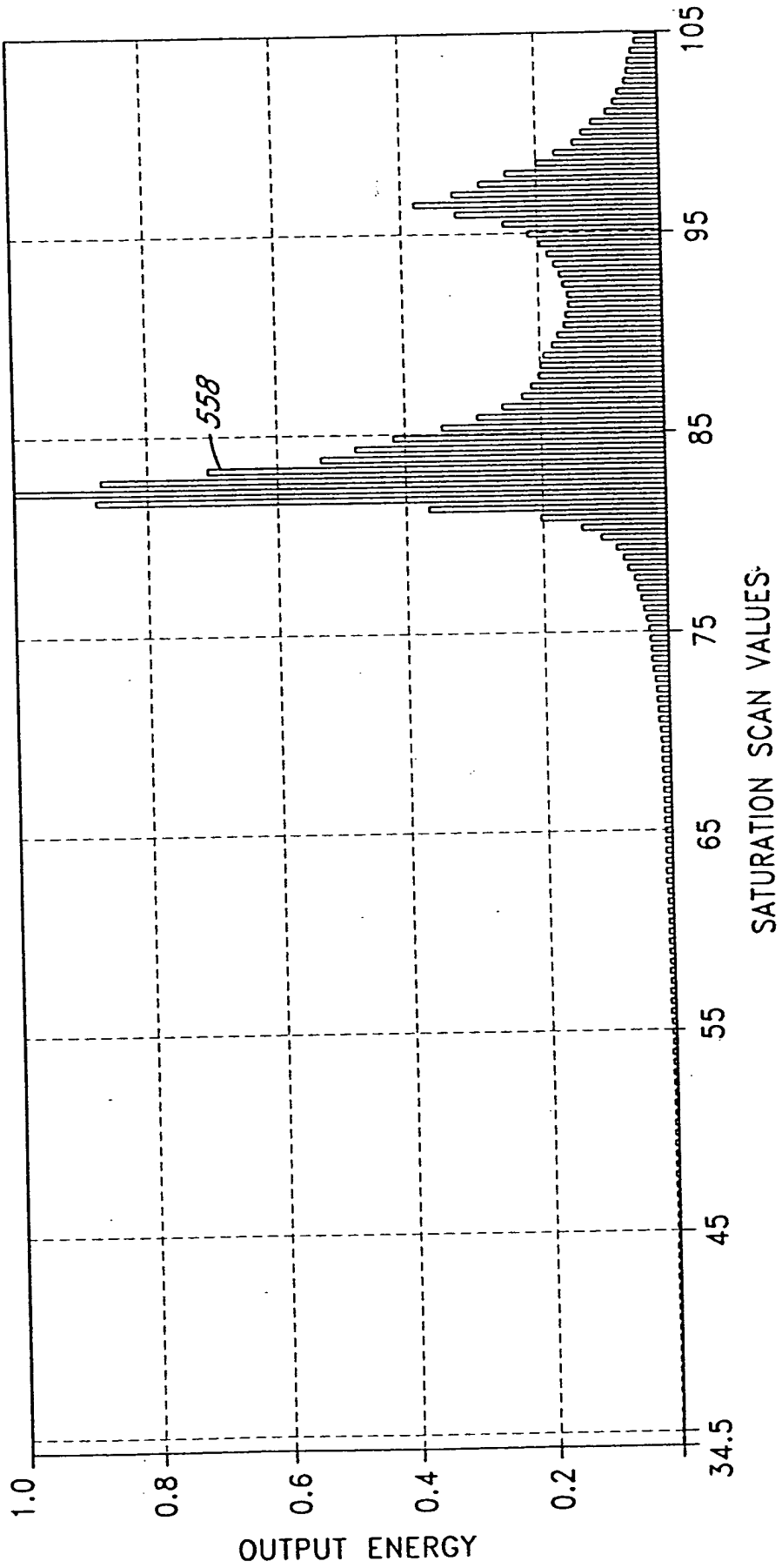

580
CLEAN WAVEFORM
573
LOWPASS FILTER
572a
571
JOINT PROCESS ESTIMATOR
SUM ERR INIT
GAMS INIT
574
NUMBER OF CELLS
MIN SUM ERR
LAMBDA
(270 SAMPLES)
BANDPASS FILTER
585
DC REMOVAL
583
REFERENCE GENERATOR
582
r_o
SATURATION EQUATION
581
570
ARTERIAL SATURATION (FROM SATURATION CALCULATION)
INFRARED (570 SAMPLES, 62.5 Hz)
RED (570 SAMPLES, 62.5 HZ)

FIG. 21a

FIG. 22


558
105
95
85
75
65
55
45
34.5
SATURATION SCAN VALUES
1.0
0.8
0.6
0.4
0.2
OUTPUT ENERGY

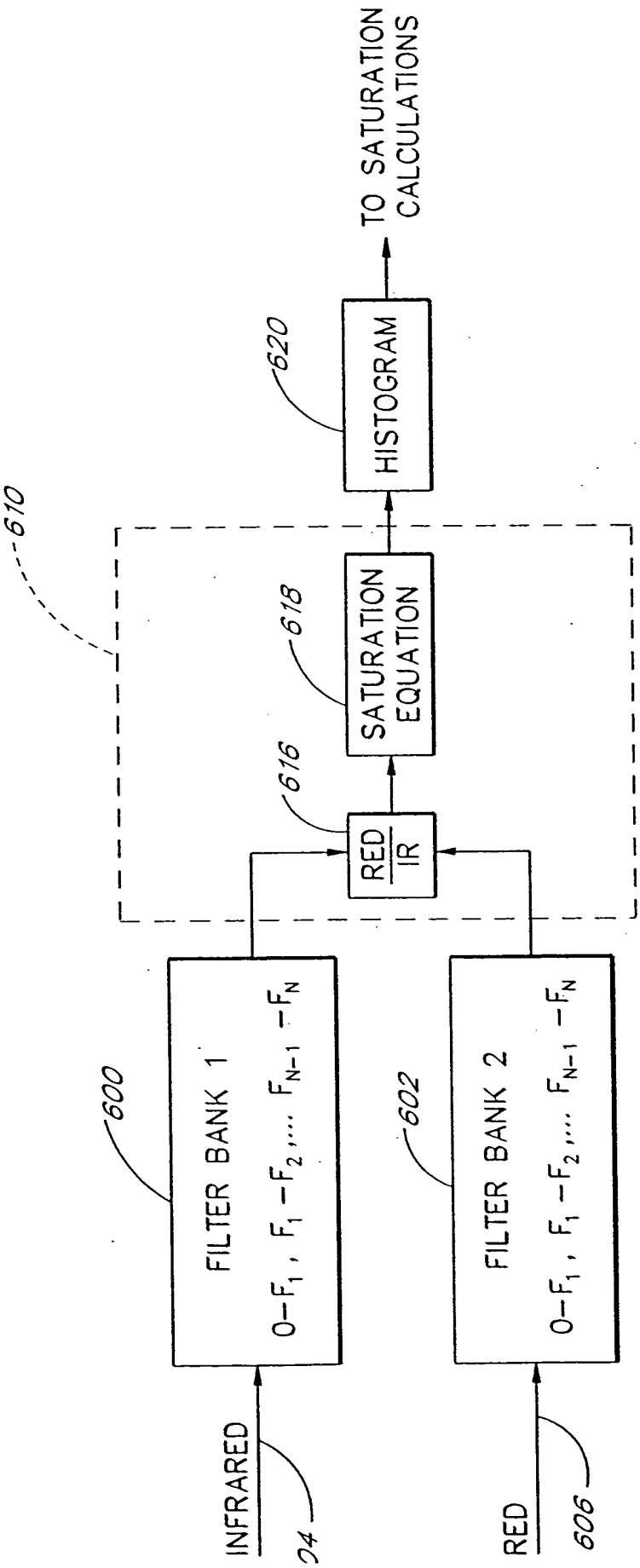
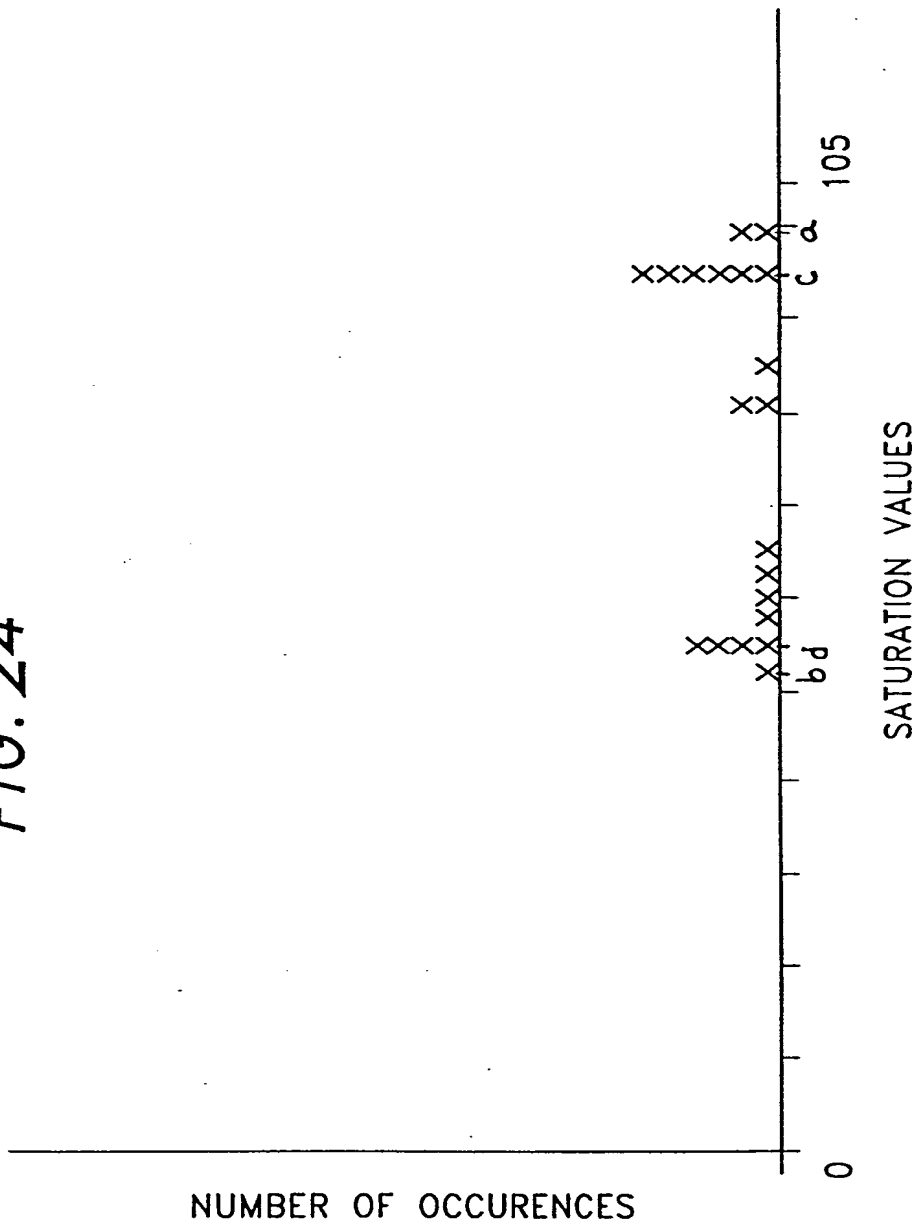

TO SATURATION CALCULATIONS
620
HISTOGRAM
610
618
SATURATION EQUATION
616
RED / IR
600
FILTER BANK 1
$0-F_1$, F_1-F_2 ,.... $F_{N-1}-F_N$
602
FILTER BANK 2
$0-F_1$, F_1-F_2 ,.... $F_{N-1}-F_N$
INFRARED
24
RED
606

FIG. 23

FIG. 24



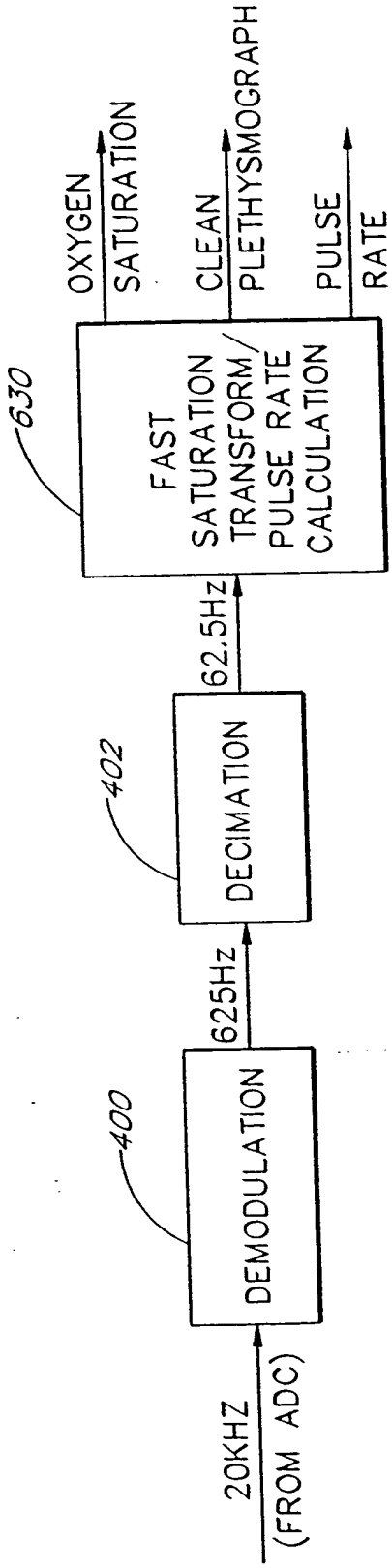

20KHZ
(FROM ADC)
400
DEMODULATION
625Hz
402
DECIMATION
62.5Hz
630
FAST
SATURATION
TRANSFORM/
PULSE RATE
CALCULATION
OXYGEN
SATURATION
CLEAN
PLETHYSMOGRAPH
PULSE
RATE

FIG. 25A

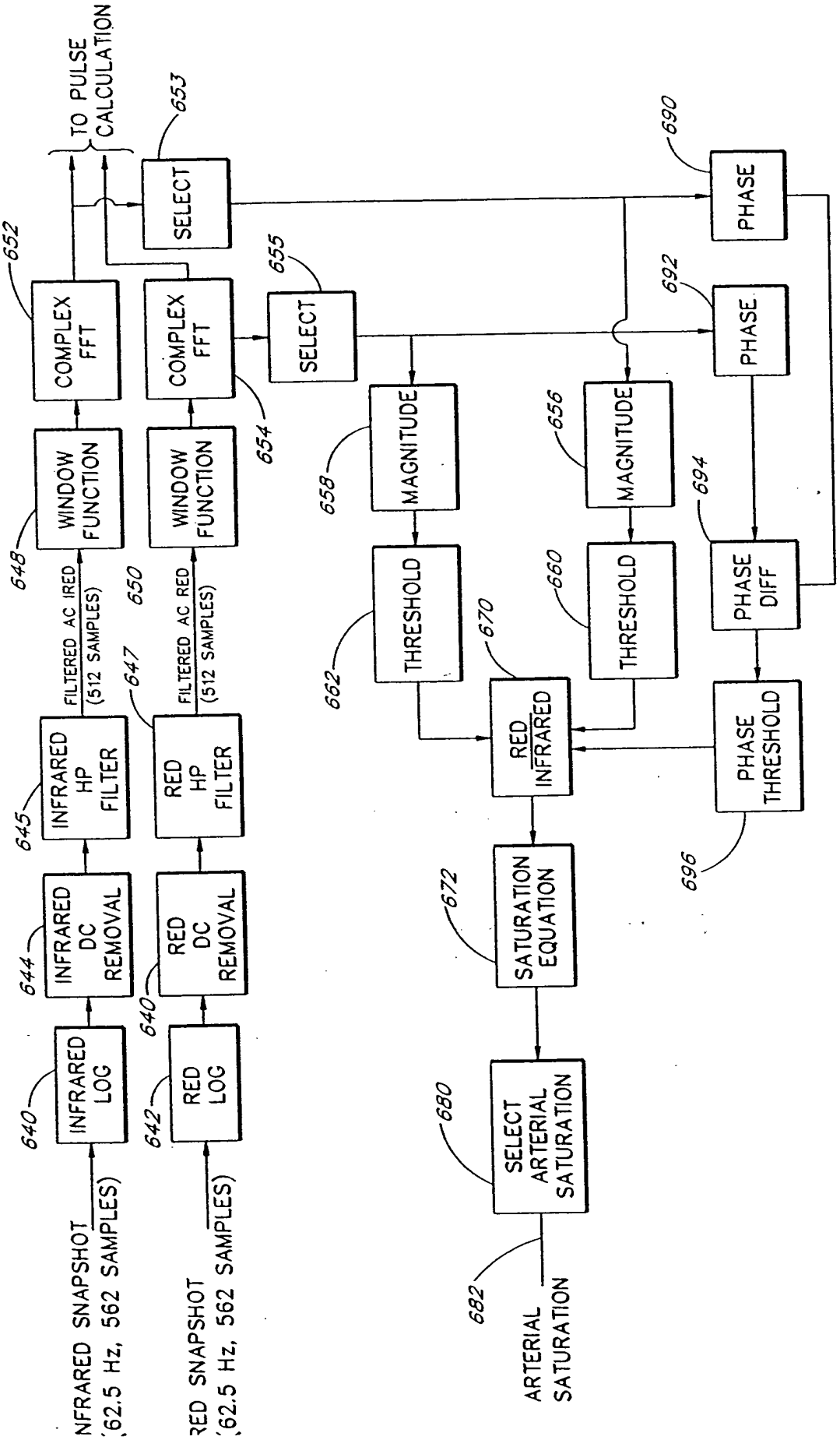

INFRARED SNAPSHOT (62.5 Hz, 562 SAMPLES)
RED SNAPSHOT (62.5 Hz, 562 SAMPLES)
640
INFRARED LOG
642
RED LOG
644
INFRARED DC REMOVAL
640
RED DC REMOVAL
645
INFRARED HP FILTER
647
RED HP FILTER
FILTERED AC IRED (512 SAMPLES)
FILTERED AC RED (512 SAMPLES)
648
WINDOW FUNCTION
650
WINDOW FUNCTION
652
COMPLEX FFT
654
COMPLEX FFT
TO PULSE CALCULATION
653
SELECT
655
SELECT
658
MAGNITUDE
656
MAGNITUDE
662
THRESHOLD
660
THRESHOLD
670
RED INFRARED
672
SATURATION EQUATION
680
SELECT ARTERIAL SATURATION
682
ARTERIAL SATURATION
690
PHASE
692
PHASE
694
PHASE DIFF
696
PHASE THRESHOLD

FIG. 25B

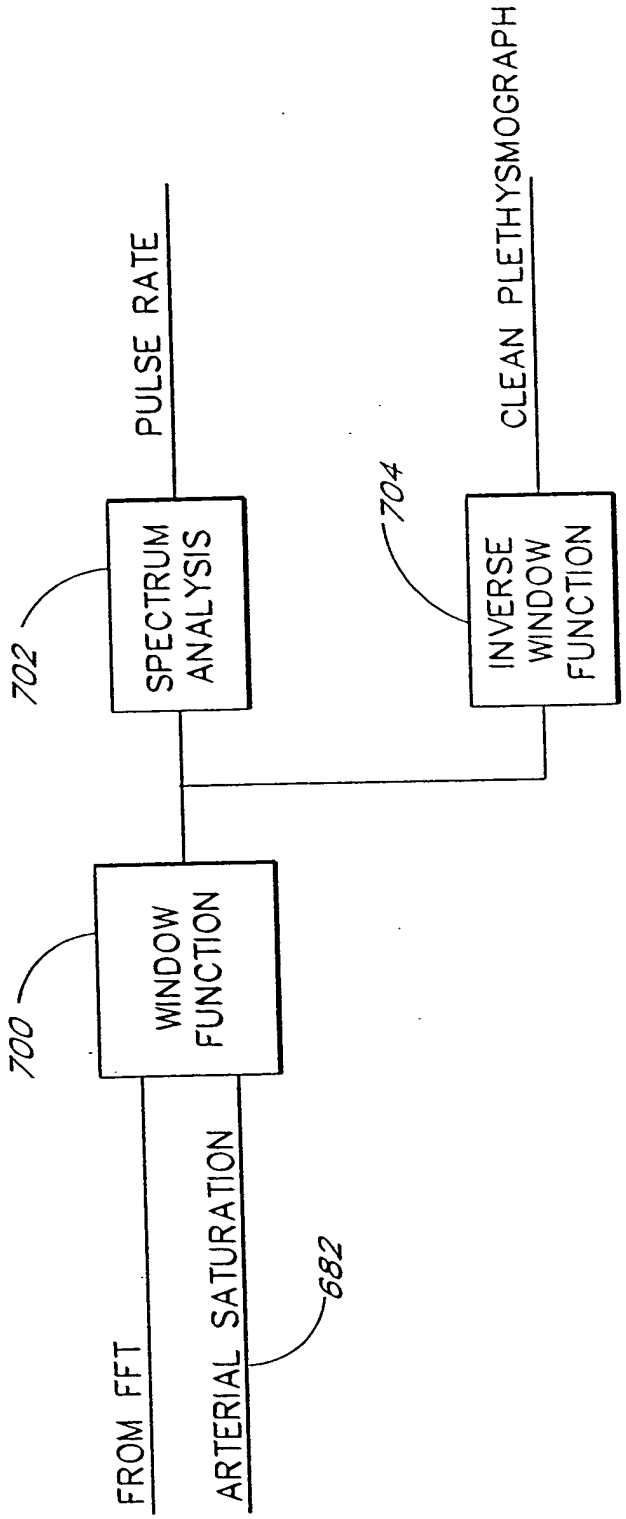

FROM FFT
ARTERIAL SATURATION
682
700
WINDOW FUNCTION
702
SPECTRUM ANALYSIS
704
INVERSE WINDOW FUNCTION
PULSE RATE
CLEAN PLETHYSMOGRAPH

FIG. 25C

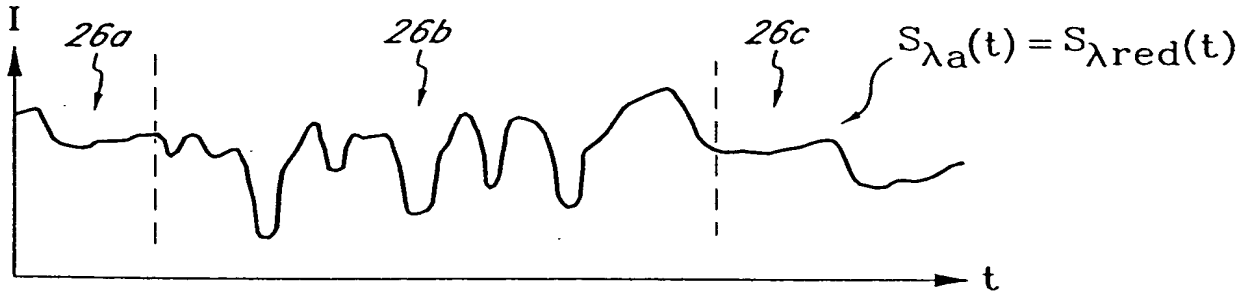


FIG. 26

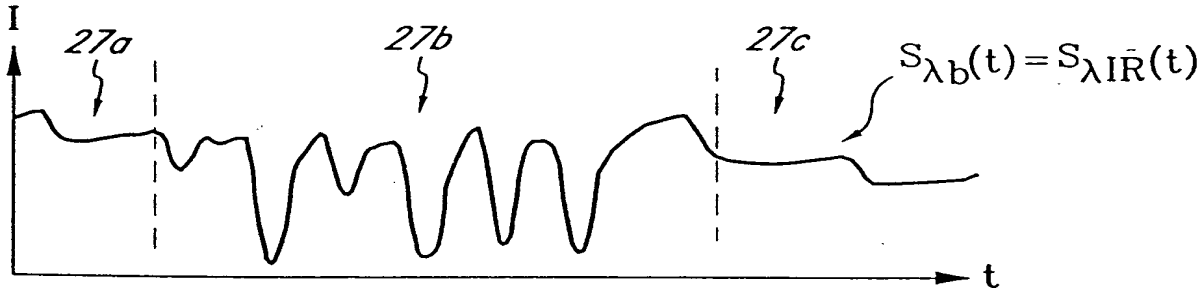


FIG. 27

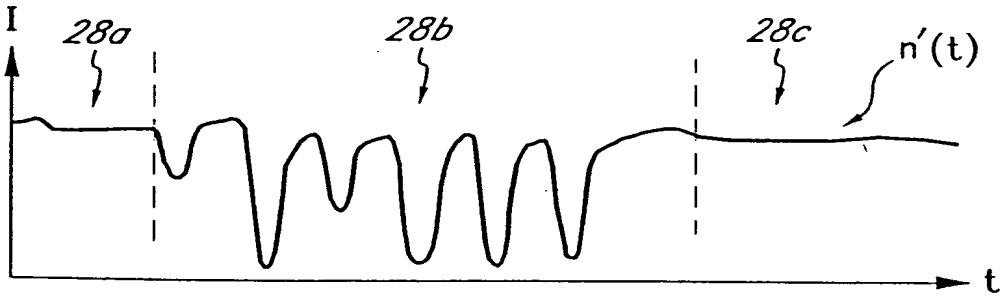


FIG. 28

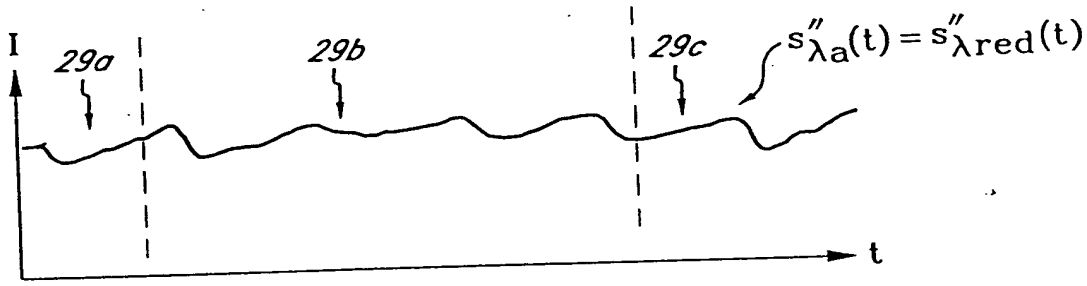

I
29a
29b
29c
$s''_{\lambda a}(t) = s''_{\lambda red}(t)$
t

FIG. 29

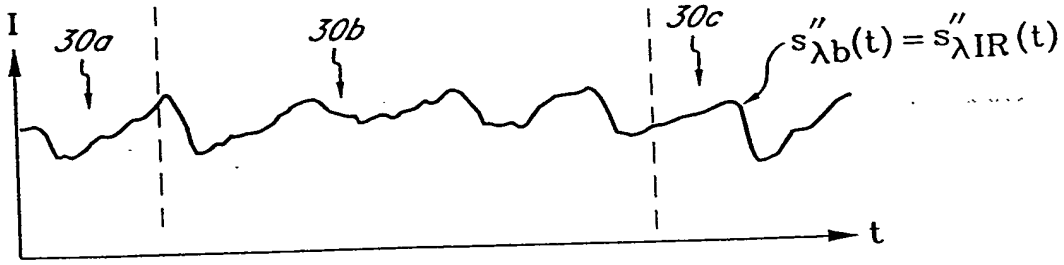

I
30a
30b
30c
$s''_{\lambda b}(t) = s''_{\lambda IR}(t)$
t

FIG. 30

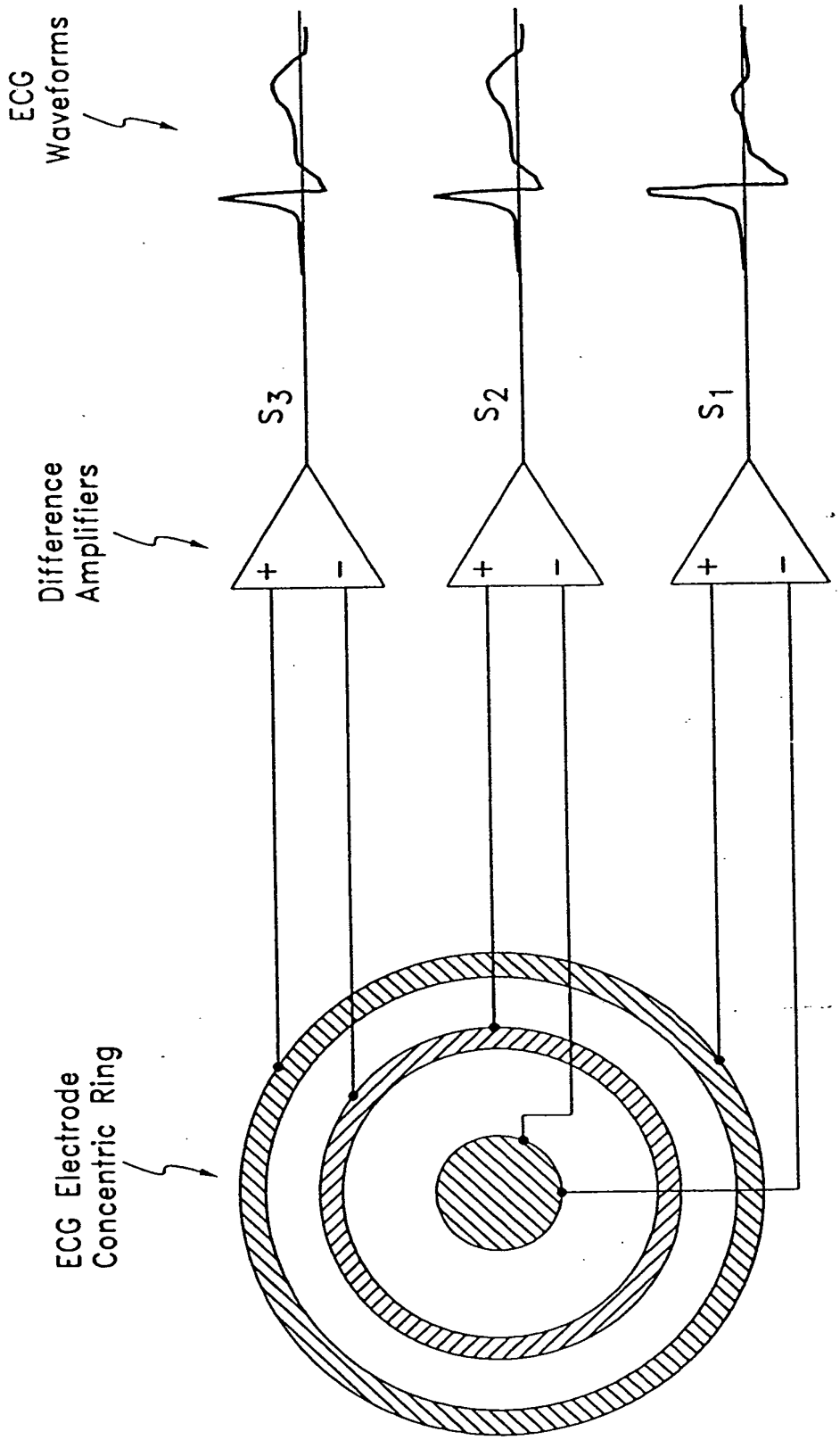

ECG Waveforms
Difference Amplifiers
ECG Electrode Concentric Ring
S3
S2
S1
+
-
+
-
+
-

FIG. 31